WORKING PAPER

MARINE ECOLOGICAL CONSEQUENCES OF WASTE DISPOSAL

by
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TABLE OF CONTENTS

I. Summary and Conclusions....1-2

II. Uncertainties....2-3

III. Impacts on Water and Sediment Quality....3-10
- Enrichment with Organic Matter and Nutrients....3-5
- Elevated Concentrations of Other Pollutants in the Water Column....5-8
  - Human Pathogens....6-7
  - Metals and Organic Chemicals....7-8
- Impacts on Sediments....8-10

IV. Impacts on the Biota....10-22
- Introduction....10
- Birds and Mammals....11-12
- Finfish and Shellfish....12-20
  - Acute Lethal Effects....12-14
  - High Body-burdens of Contaminants....15-17
    - Shellfish Contamination....15-16
    - Finfish Contamination....16-17
  - Other Effects on Finfish and Shellfish....18-20
- Submerged Aquatic Vegetation....20-21
- Benthic Organisms....21-22

V. Geograpahical Variations in Emissions and Impacts....23-47
- Pacific: Northwest....23-25
  - Puget Sound....24-25
- Pacific: California and Hawaii....25-30
  - San Francisco Bay....26-28
  - Southern California Coastal Waters....28-30
- Gulf of Mexico....30-23
- Atlantic: Southern States....33-37
  - Pamlico Albermarle Estuarine Complex....35-37
- Atlantic: Northern States....37-47
  - Chesapeake Bay....40-42
  - The New York Bight....42-43
  - Long Island Sound....43-44
  - Narragansett Bay....44-45
  - Buzzards Bay....45-46
  - Boston Bay....46-47

Footnotes....48-57

Unabridged Bibliography....58-121

BOXES

Box 1: Hypoxia Along the Southern Louisiana Coast..... .4A
Box 2: Environmental Stress in the Mississippi Sound.....31A

FIGURES

Figure 1. Extent of Oxygen Depletion in Bottom Waters of the Louisiana Shelf During 1985.....4B

Figure 2. Offshore Shrimp Abundance in Relation to Bottom Dissolved Oxygen Concentration in Louisiana Coastal Waters...4C

Figure 3. Volume of Water in Chesapeake Bay with Low Levels of Dissolved Oxygen, 1950 to 1980.....4D

Figure 4. Concentration of Nickel and Hydrocarbons in Narragansett Bay, Rhode Island, in Relation to distance from Discharge Points.....5A

Figure 5. Concentrations of Cadmium in Sediments Along the Northeast Atlantic Coast During 1984.....8A

Figure 6. Canvasback Duck Population on the Chesapeake Bay, 1954-1985.....11A

Figure 7. PCB Concentrations in the Livers of Fish From Selected Sites.....17A

Figure 8. Relationship Between Size of Kelp Beds and Quantity of Solids from Municipal Discharges at a Southern California Site, 1937-1981.....21A

Figure 9. The five Coastal Pegions of the United States Used in This Report.....23A

Figure 10. Chlorinated Hydrocarbons in White Croaker Muscle from the Southern California Bight.....29A

Figure 11. Annual Change in Total DDT Mass Emission Rate from Major Southern California Ocean Outfalls, 1971-1979; and Changes in Length of Coastline Bearing Mussels Contaminated by DDE, 1971-1978.....30A

Figure 12. Environmental Stress In the Pascagoula Area of Mississippi Sound.....31B

Figure 13. Fishing Closure Areas Established by the Massachusetts Department of Public Health in the New Bedford Harbor.....46A

Figure 14. Major Beaches of Boston Harbor Affected

by Sewage Overflows.....47A

TABLES

Table 1. Classification of Shellfish Growing Waters, 1985.....15A

Table 2. Intensive or "hot spot" Investigations for Potential Regulatory Action by Water Quality Authorities in California Marine Estuarine Waters, 1981-1984.....16A

Table 3. Factors Possibly Important in Contributing to the Decline of Certain Populations of Anadromous Fish in Coastal Waters of South Atlantic and Gulf States.....20A

Table 4. List of Data Concerning Historic Anthropogenous Impact on Seagrass Meadows in Florida.....20B

Table 5. Selected Toxic Contaminants in Puget Sound: Their Distribution, Sources, Effects and Trends.....25A

Table 6. Pathological Conditions in Fish from Puget Sound.....25B

I. SUMMARY AND CONCLUSIONS

This document summarizes the observed effects on marine resources of waste disposal activities. It first briefly describes the nationwide impacts of pollutants on water quality, sediment quality, and marine organisms. Following this is a region-by-region summary of the impacts.[1] The regional discussion illustrates the broad geographical variations in impacts, while providing greater detail on specific problems and water bodies. Extensive references and a bibliography are provided to support the statements made in this document and to assist those readers interested in obtaining more detailed information.

The precise connection between pollutants and impacts on marine resources often is poorly understood; likewise, the full implications to humans of the marine impacts are not exactly defined. Given informational shortcomings, we do not possess a clear and complete picture of the extent of the impacts of waste disposal throughout the country. Despite the problems, however, the available evidence is sufficient to support the following general conclusions.

Marine resources have been and will continue to be affected by a wide range of natural and human perturbations, including pollutant discharges. The discharges enter marine waters directly, and indirectly via inland freshwaters. Most impacts attributable to pollutants from waste disposal have been observed in estuaries and coastal waters -- generally the most productive marine waters. Impacts vary widely in quality and in distribution among water bodies and organisms.

Every region contains some areas which have suffered serious negative impacts from pollutants discharged by waste disposal activities. The most serious impacts from permitted sources appear to result from discharges of nutrients, pathogens, metals, and synthetic organic compounds. Even when

present in the water column and sediments in very small quantities, certain metals and synthetic organic chemicals can result in chronic, persistent, and serious effects on organisms.

Where trends in impacts over the last ten to fifteen years are discernable, they have been mixed. They have varied among specific pollutants, species, and locations. In some cases improvements have been observed, in other cases deterioration is evident. Sometimes no clear trend appears.

II. UNCERTAINTIES

It is only with great difficulty and uncertainty that causal links can be drawn between waste disposal and changes in marine ecosystems. Changes in the marine environment may result not only from the waste disposal practices considered here (i.e. only those point-source discharges which require permits), but also from other variables including pollutants from non-point sources, natural perturbations, fishing, and other human-induced environmental changes (such as habitat destruction or alterations resulting from river diversions). Where pollutants are involved, they may emanate from any combination of surface runoff, transport from distant sources by ground water or surface waters, direct discharges by industries or municipalities, and atmospheric deposition.

In those instances where pollutants do significantly affect the marine environment, various factors may mitigate against the development of an awareness and understanding of the impacts. Though in some cases impacts are clearly evident, they often are subtle, detected only with great difficulty and expense; or they escape detection altogether. Impacts in some cases are not observed for many years or even decades after the release of the pollutant. They may occur at great distances from the point at which pollutants originally are released.

Even where impacts are noted, it frequently is very difficult to conclusively link them to specific pollutants. The quantity and quality of pollutants in a water body may not be fully known, nor may the ultimate source of the pollutants be evident. The wastes may act synergistically with each other or with other variables.

Consequently, establishing precisely the causes of past and present changes is a formidable task. Likewise, predicting future impacts -- especially long-term impacts on populations and communities of marine organisms -- is extraordinarily difficult and our ability to do so is rudimentary.[2] The situation is one characterized by a lack of accurate and useful information, and difficulties in obtaining and digesting information which does exist. For the sake of brevity, the full degree of uncertainty in each particular instance discussed in this document is not discussed in detail. May it suffice to emphasize at the outset that considerable uncertainty exists and that great caution should be exercised in drawing conclusions from the evidence presented herein.

III. IMPACTS ON WATER AND SEDIMENT QUALITY

ENRICHMENT WITH ORGANIC MATTER AND NUTRIENTS

Among the impacts of pollutants on the marine environment, perhaps the most conspicuous and widespread are those associated with the introduction of organic matter and nutrients into marine waters. This results in eutrophication, a phenomenon evident in every region of the country.

The impacts of eutrophication range from stressing individual organisms (which in turn may increase incidence of disease or abnormalities) to major ecological changes. Nutrient enrichment in some instances may contribute to massive blooms of tiny photosynthetic[3] organisms, sometimes dubbed "green

tides," "brown tides,"[4] or "red tides." These organisms may directly and adversely affect -- and even kill -- other marine organisms and humans.[5] [6] Under extreme conditions, eutrophic conditions also may lead to the severe depletion of dissolved oxygen, known as hypoxia; hypoxia may also be caused or aggravated by the introduction to marine waters of oxygen-demanding pollutants such as organic matter.

Hypoxic areas vary widely in magnitude, from a fraction of a square mile to thousands of square miles. Among large and regularly occurring hypoxic waters are an area off the Louisiana coast recently estimated to extend over 8,000 km^2 (See Box 1);[7] and a portion of the Chesapeake which has covered an area of about 3,000 km^2 (See Figure 3).[8] The most dramatic consequences of extreme hypoxia are mass kills of organisms, the magnitudes of which vary considerably among incidents. Various other impacts also have been observed. In the Chesapeake Bay, for example, nutrient enrichment is a major cause of declines in submerged aquatic vegetation, valuable fisheries, and waterfowl populations; and changes in benthic diversity, abundance, and community structure.[9]

While other factors (including completely natural variables) may also cause hypoxia, its occurrence around the country often has been linked, with varying degrees of certainty, to human activities, including waste disposal. Many different pollutant sources, including both point sources (particularly municipal discharges) and runoff, can contribute to hypoxic conditions.

Eutrophication and hypoxia are serious and regularly recurring problems in many waterbodies.[10] Hypoxia appears to be least extensive along the Pacific coast; conversely, the Atlantic coast and particularly the Gulf of Mexico appear to be characterized by extensive hypoxia[11] For example, extensive hypoxia has been found along the southern coast of Louisiana (see Box 1).[12] Hypoxia also

BOX 1: HYPOXIA AND THE LOUISIANA SHELF

The coast of southern Louisiana is dominated by mudflats and marshes; these marshes are among the most productive ecosytems on earth. Beyond these areas, the wide continental shelf descends gently and smoothly. Discharging into the coastal waters -- and of overwhelming importance -- are the Mississippi and Atchafalaya Rivers. Together, they drain over forty percent of the continental U.S. This includes much of the nation's agricultural land, as well as many major cities and idustrialized areas.

This coastal environment is extremely productive and valuable. Sizeable numbers of birds, including migrating shorebirds and waterfowl, are found in the area. Large populations of fish and shellfish spend all or portions of their life cycles there. These in turn support a large fishing industry, centered around menhaden and shrimp. The magnitude of Louisiana catch in 1985 was 1.7 billion pounds, far more than landed by the second place state, Alaska. The value of the catch was nearly $230 million. When major U.S. ports are ranked by the weight of their annual catches, three of the top four are in southern Louisiana.[1] Also important are Louisiana's marine recreational fisheries, whose total economic impact is estimated to be $450 million.[2]

This productivity is being undermined by extensive and periodic hypoxia -- a condition where dissolved oxygen levels in the water are extremely low. The precise extent, duration, severity, and consequences of the hypoxia are not known. Nor is it known how conditions are changing from one year to the next. It is, however, certain that large areas of the northern Gulf of Mexico are affected and that few if any shrimp or bottom-dwelling fish are caught in such areas.

One recent study reported extensive hypoxic waters along the coast of Louisiana in 1985 (See Figure 1).[3] An earlier study found that the combined catches of brown and white shrimp and the total fish biomass tended to decline in these areas as dissolved oxygen concentrations decreased (See Figure 2).[4] Hypoxic conditions occurring during critical early periods of the shrimp life cycle also may have resulted in more generalized declines in stocks.

The exact causes of the widespread hypoxia are not known. The extent to which humans have contributed to or caused the problem -- and specifically the degree to which pollutants from permitted sources are responsible -- cannot be defined precisely. It does appear, however, that the waters of the Mississippi and the Atchaflaya, laden with nutrients and organic materials, are major contributors the problem. To the extent that humans contribute to those loadings, they may be responsible in part for the hypoxic conditions.

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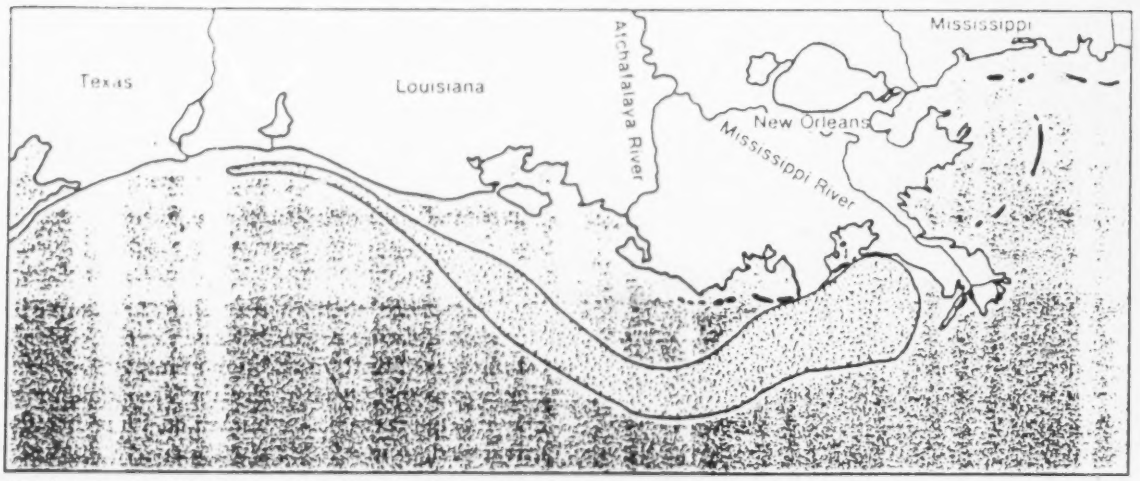
[1]Ref. 891A.

[2]Ref. 64.

[3]Ref. 637.

[4]Ref. 654.

Figure 1 —Extent of Oxygen Depletion in Bottom Waters of the Louisiana Shelf, July 1985

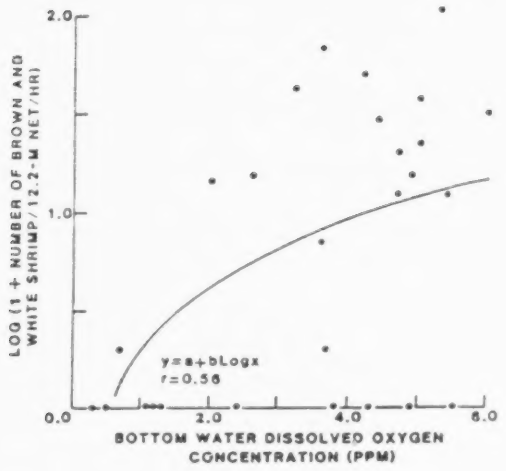


Stippled area depicts bottom waters with dissolved oxygen concentrations less than 2 milligrams per liter (a condition known as hypoxia). Most animal life cannot survive for long in water with such low oxygen concentrations.

SOURCE: N. Rabalais and D.F. Boesch, *Extensive Depletion of Oxygen in Bottom Waters of the Louisiana Shelf During 1985* (draft manuscript, 1986).

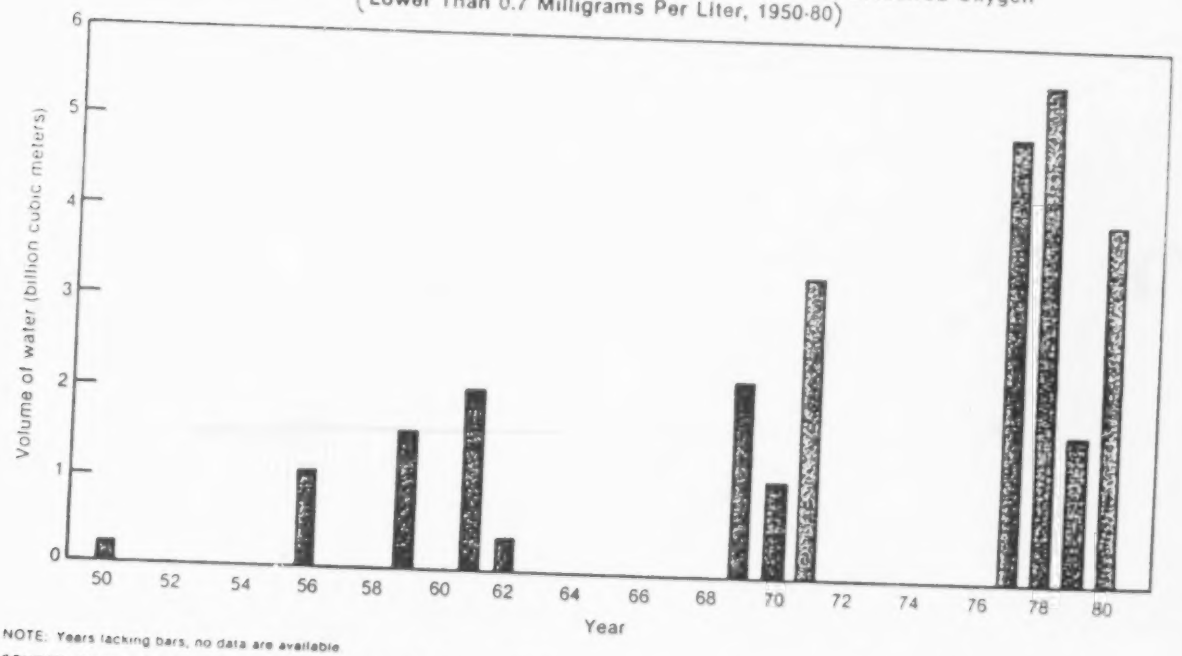
FIGURE 2

Offshore Shrimp Abundance in Relation to Bottom Water Dissolved Oxygen Concentration in Louisiana Coastal Waters.



Source: Renaud, Maurice L., "Hypoxia in Louisiana Coastal Waters During 1983: Implications for Fisheries," Fishery Bulletin, 84 (1): 19-26, Jan 86.

Figure 3 –Volume of Water in Chesapeake Bay With Low Levels of Dissolved Oxygen (Lower Than 0.7 Milligrams Per Liter, 1950-80)



NOTE: Years lacking bars, no data are available.

SOURCE: Office of Technology Assessment, 1987, after U.S. Environmental Protection Agency, Region 3, Chesapeake Bay Program, *Chesapeake Bay: A Profile of Environmental Change*, PB 84119197 (Philadelphia, PA, 1983)

has been a common occurrence in the New York Bight; its causes are multiple and include natural factors as well as pollutant inputs from raw sewage, sewage sludge, and other waste materials.[13]

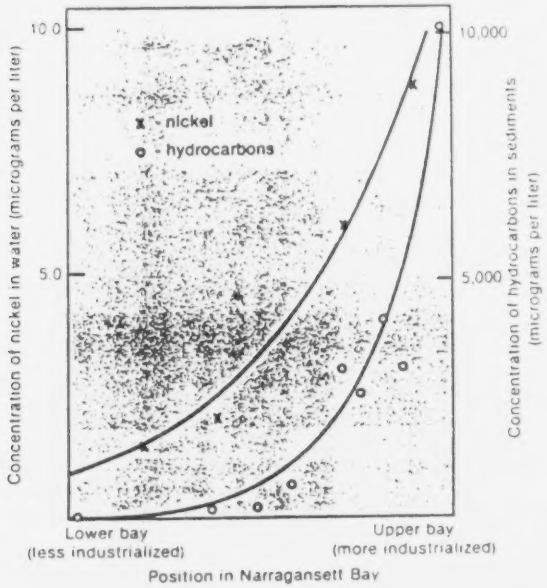
Trends around the country are mixed. In some areas, the problems have been alleviated, to a large degree because discharges of organic matter and nutrients have been reduced in those waters.[14] In other instances, the problems have grown in severity, either because quantities of nutrients and organic matter have increased, or because other changes have reduced the natural system's capacity to accommodate the discharges.[15]

ELEVATED CONCENTRATIONS OF OTHER POLLUTANTS IN THE WATER COLUMN

In addition to organic matter and nutrients, other pollutants are discharged into marine waters in large quantities. Among these are pathogens, metals, and organic chemicals (such as chlorinated and aromatic hydrocarbons). Where contamination has been detected, concentrations vary widely both in time and space, from levels scarcely above the threshold of detectability to extremely high levels, depending on many factors. Contamination tends to be greatest in the vicinity of estuaries flanked by heavy urban or industrial development, or near estuaries which receive pollutants from developed areas further upstream (See Figure 4). Contamination also tends to be most serious near municipal and industrial outfalls, and in the vicinity of major dump sites for sewage sludge or other polluted materials.

Even at a given location and time, contamination may vary considerably according to the vertical position in the water column. Some pollutants may concentrate at the very surface of the water-column (the surface "microlayer"[16]), an ecologically important zone where the presence of pollutants may be particularly damaging. For example, in the urbanized areas of Puget Sound, the microlayer has been found to contain relatively high concentrations

Figure 4 .—Concentration of Nickel and Hydrocarbons in Narragansett Bay, Rhode Island, in Relation to Distance From Discharge Points



As in many other locations in the United States, concentrations of pollutants in Narragansett Bay tend to be greatest near discharge points, especially where many such discharges are concentrated in a highly industrialized or urbanized area. Note that one microgram equals one-millionth of a gram.

SOURCE: Save The Bay, Inc., *Down the Drain: Toxic Pollution and the Status of Pretreatment in Rhode Island* (Providence, RI: September 1986).

of some pollutants. Among these were polynuclear aromatic hydrocarbons, present at concentrations which in many cases were acutely toxic to floating flatfish eggs in laboratory experiments. It is believed that the pollutants account in part for the lower quantities of flatfish eggs and other organisms found in the microlayer in the developed areas of the Sound.[17]

The presence of pollutants in the water column is important in three respects. First, as just suggested, marine organisms may be affected by the direct exposure to the polluted water. For example, evidence from the Chowan River in North Carolina suggests that herring have detected and avoided pulp mill effluent in the river, to the detriment of some fishermen[18] and in Puget Sound, some samples of polluted bottom water were found to cause sublethal toxic effects in specific organisms.[19] Such initial and direct impacts may give rise to further ecological repercussions.

Second, the pollutants may be transported to other locations and transferred to sediments or to the atmosphere, thereby creating additional opportunities for exposure to living organisms and for ecological impacts. Third, in addition to impacts on marine organisms, elevated levels of these pollutants may reach a point where human health is directly threatened. This may prompt management actions such as closures of beaches and shellfish growing areas, measures which frequently have been taken as a result of contamination by fecal coliform bacteria.

Human Pathogens. The discharge of pathogens is a common occurence, from combined sewage overflows, municipal treatment plants, runoff, raw sewage, and boats in marinas and elsewhere. High levels of fecal coliform bacteria in the water frequently result in the imposition of harvesting restrictions in shellfishing areas around the country (see subsequent section on shellfish contamination). They also have resulted in temporary or permanent beach closures in some areas, particularly along the north Atlantic coast.[20] The

problem appears to be less common in other regions of the country, but complete information on the extent of beach closures throughout the nation is not readily available and trends are not clearly discernable.

In some areas -- such as San Francisco Bay [21] and Chesapeake Bay [22] -- fecal coliform contamination of the water is not as serious as it was ten or fifteen years ago.[23] Where this improvement has occurred, it usually has resulted from greater levels of sewage treatment.

Conversely, such contamination has not been reduced or has worsened in other areas, particularly those experiencing high population growth and rapid development.[24] Degradations is most evident in areas with growing numbers of residences with septic systems and increasing numbers of small boats. In Louisiana, for example, many growing coastal communities do not have sewers. Where sewage treatment facilities are available, in many cases they need to be upgraded; inadequately treated sewage is being discharged. The problems are reflected in the fact that coliform contamination is considered by state officials to be the most common problem in the state's coastal waters.[25] These threats to water quality are expected in these and other quickly developing regions to grow over the next decade.[26]

Metals and Organic Chemicals. Also common is the contamination of waters with metals and organic chemicals.[27] Concentrations of some metals and organic chemicals (such as DDT[28]) in the water column have been reduced in many areas over the last fifteen to twenty years. This often has occurred as emissions of these pollutants have been substantially diminished from specific point sources, usually because of curtailed production of the wastes or because of greater waste treatment by industrial and municipal entities.[29] For example, discharges of most key metals and organic chemicals into New York Harbor declined during the 1970s and early 1980s.[30]

But there also are areas where improvements have not occurred, or where concentrations of specific pollutants have increased.[31] This has been especially true where particularly rapid residential, agricultural and industrial growth has resulted in greater emissions from both point and non-point sources. For example, monitoring data from the lower St Johns River, Florida, indicate that concentrations of waterborne toxic metals increased from 1970 through 1980; the same area in the mid-1980s witnessed an outbreak of a fish disease, the exact causes of which are unknown.[32]

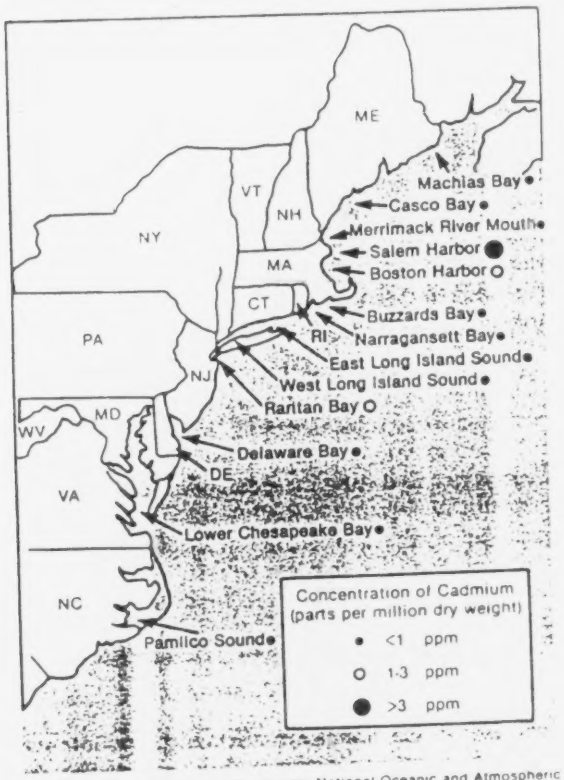
IMPACTS ON SEDIMENTS

In many parts of the country -- in every region -- there are areas where sediments have been physically, chemically and biologically altered by waste disposal activities. These include areas where large volumes of material (such as industrial wastes) have been dumped; in the vicinity of outfalls; adjacent to industrial and urban areas; and in and around estuaries carrying substantial pollutant loads from upstream. The character of sediment alterations varies widely, as do their consequences and origins.

Especially problematic are heavy loadings of organic matter and nutrients; and the chemical contamination of sediments with pollutants such as metals, polychlorinated biphenyls (PCBs) and other chlorinated hydrocarbons, polynuclear aromatic hydrocarbons (PAHs), and pathogens. Polluted sediments have been found around the country, though they appear to be most prevalent and severe in the estuaries and coastal areas of the Northeastern U.S. (for example, see Figure 5).

In some cases, the consequences of the sediment alterations are relatively apparent and serious. Such is the case, for example in areas characterized by extremely high concentrations of particularly toxic pollutants. Among such areas are very polluted portions of Puget Sound like Commencement Bay

Figure 5.—Concentration of Cadmium in Sediments Along the Northeast Atlantic Coast During 1984



SOURCE: U.S. Department of Commerce, National Oceanic and Atmospheric Administration, Ocean Assessments Division, *Progress Report and Preliminary Assessment of the Findings of the 1984 Benthic Surveillance Project* (Rockville, MD: 1986).

and Everett Harbor,[33] the Southern California Bight,[34] and several areas of the Northeast such as Buzzard's Bay.[35] Many other areas exhibit various mixes and concentrations of pollutants with specific subsequent effects on the biota.[36]

In Southern California, for example, the accumulation of solids discharged by several ocean outfalls, in combination with other environmental changes associated with the discharges, has affected the distribution and abundance of benthic organisms over an area of approximately 108 km^2.[37] Other than such extreme cases are many other varied examples, each with particular mixes and concentrations of pollutants; and with specific effects on the biota, ranging from little or no significant impacts to relatively serious consequences.[38]

To the extent that restrictions have been imposed on waste disposal over the last 15 to 20 years, sediment alteration by some pollutants has been curtailed. If pollutants are present, they eventually may be broken down into less harmful byproducts. Or subsequent sediment deposition may bury the pollutants and prevent further exposure to living organisms. But serious problems from polluted sediments have persisted -- and will continue to persist -- for two reasons.

First, as indicated above, even though releases of some pollutants have been curtailed, a growing variety and quantity of pollutants continue to be released to the water column and make their way to the sediments.[39] Second, the sediments often act as a repository for such pollutants, holding them for days, years, decades or even centuries. Polluted sediments can continue to affect organisms -- for example, through the release of pollutants (such as nutrients) to the water column or through ingestion by bottom-dwelling organisms.[40]

For example, DDT and its metabolites are presently found in extremely high concentrations in sediments in some parts of Southern California. These pollutants originate primarily from DDT discharged by industry to the marine

environment between 1947 and mid-1971. Similarly, a long stretch of the Hudson River bed and a sizeable proportion of nearby coastal waters has been polluted by PCBs discharged between circa 1950 and 1976. After high levels of PCB contamination were found in fish, industrial releases were terminated and, in 1976, commercial fishing of the river's striped bass was banned. Ten years later, elevated levels continue to occur and the ban has been extended over the entire state of New York.[41]

IMPACTS ON THE BIOTA

INTRODUCTION

Pollutants from waste disposal activities and other sources have affected marine organisms and ecosystems in many different ways. Chronicled below are some of the major impacts on marine organisms which have been associated with waste disposal activities. The impacts on these organisms vary widely, from acute and lethal to relatively minor, from extremely adverse to relatively beneficial. The geographic scale of impacts also varies as well, ranging from very small areas to many thousands of square miles.[42]

Some organisms are highly exposed to waste disposal activities and pollutants. Among these are bottom-dwelling (benthic) organisms and those which spend all or part of their lives in coastal waters or estuaries. Particularly susceptible to effects are organisms which inhabit in polluted waters during life-stages when they are very sensitive to environmental perturbations.

For example, striped bass spend their early life-stages in or near estuaries and during that time are very sensitive to some substances (such as copper, cadmium and aluminum) which may be contained in waste discharges. High mortality-rates observed during these stages appear to be related to the presence of pollutants and other factors. Low survival-rates during the first 60 days of life are said to be a major reason for the precipitous declines in striped bass stocks in recent years.[43]

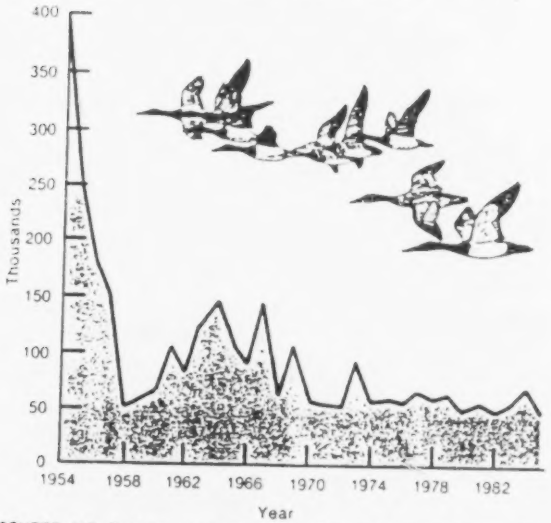
BIRDS AND MAMMALS

Birds and mammals may be affected by pollutants in several ways. In some cases, they may be affected indirectly when pollutants alter their habitat or food supplies. This appears to have been the case with canvasback ducks in the Chesapeake Bay. Pollutants appear to be largely responsible for drastic declines in the extent of the Bay's seagrasses, including wild celery, the preferred food of the ducks. This has contributed to a precipitous decline in their populations in the Bay (See Figure 6).[44]

Most of the strongest evidence linking pollutants to impacts on birds and mammals concerns effects which occur when they ingest a pollutant or a metabolite of a pollutant. Particularly important are pollutants, such as some chlorinated hydrocarbons, which both are persistent and tend to increase in concentration as they are transferred through the food web. Marine birds and mammals are often at relatively high trophic levels and are particularly susceptible to such "biomagnification."

Numerous studies have documented elevated concentrations of some pollutants in birds or mammals.[45] In a few important instances, evidence indicates that the pollutants originated with waste disposal activities, and that exposure to the pollutants is correlated with effects on those organisms.[46] The full consequences of such contamination in birds and mammals are not always known, but in addition to elevated body-burdens, impacts such as reproductive impairments have been observed. Perhaps the best known example involved discharges of DDT into Southern California waters. Elevated concentrations of organochlorine chemicals and subsequent declines in brown pelican populations and several other bird species were linked to the consumption of fish contaminated with DDT and its metabolites.[47] Reproductive problems in sea lions also have been associated with organochlorine pollutants.[48]

Figure 6.—Canvasback Duck Population on the Chesapeake Bay, 1954-85



SOURCE: U.S. Department of the Interior, Fish and Wildlife Service, *The Canvasback* (Annapolis, MD: 1985).

Other less dramatic -- yet nevertheless significant -- examples exist elsewhere in the country. For example, three waterbird species nesting in Galveston Bay, Texas, have been found to contain elevated levels of several heavy metals and selenium, in some cases at levels associated with adverse affects (such as impaired reproduction). Selenium can enter marine waters from numerous natural and anthropogenic sources, including both industrial and municipal wastes.[49]

Reduced emissions of some pollutants have resulted in noticeable ameliorations; population declines have in some cases been reversed and body-burdens of pollutants have fallen. In particular, the banning of DDT production and disposal resulted in a reversal of the decline in brown pelicans.[50] Nevertheless, high concentrations of pollutants continue to be documented in birds and mammals, along with other pollutant-related impacts[51]. For example, several studies have found chlorinated hydrocarbon levels in marine cetaceans (i.e. dolphins, porpoises) off the California coast that are higher than concentrations known to have been reported in marine cetaceans anywhere else in the world -- the blubber of one bottlenose dolphin contained DDT concentrations higher than 2,000 ppm wet weight.[52]

FINFISH AND SHELLFISH

ACUTE LETHAL EFFECTS

Some pollutants or combinations of pollutants in large enough quantities quickly will kill finfish and shellfish. The mechanisms by which this occurs vary from the depletion of vital oxygen, associated with discharges of nutrients and organic matter to the crippling of an organism's nervous system by certain toxic organic compounds. These effects have been established both by laboratory experiments and by field observation. However, the full extent to which this

actually occurs in the field is difficult to measure, as individual organisms which are seriously debilitated or dead very quickly disappear (they are eaten by others).

One type of evidence which does arise in the field -- and which is uniquely compelling -- arises when large numbers of organisms are killed at once by pollutants. Reports filed voluntarily by the states to the EPA provide some information on pollution-caused fish-kills.[53] Additional data are available from other sources, including state 305(b) reports,[54] other state documents, and state officials. These indicate that the occurrence of such mass mortalities varies around the country. They appear to be least frequent along the Pacific coast, but are considerably more common and serious in the Northeast. The greatest problems exist in the Gulf of Mexico and along the southern Atlantic Coast, where frequent fish kills result from hypoxic conditions that are caused by a combination of natural and anthropogenic factors.[55]

The magnitude of the kills varies widely. The largest incidents can involve millions of fish. The fish species reported as killed often consist mostly of commercially valued species. For example, 109 fish kills were reported in the State of Maryland in 1985; an estimated 4.6 million fish were killed, 97 percent of which were menhaden, a very abundant and important commercial species. The majority of the kills investigated in Maryland -- some involving hundreds of thousands of fish -- occurred in estuarine waters in the Chesapeake Bay. Most resulted from hypoxic conditions caused by many factors, including an abundance of nutrients.[56]

While the causes of fish kills are not always clearly and fully understood, evidence suggests that waste disposal activities in many instances are significant contributors. Most kills occur in estuaries and are caused by low levels of dissolved oxygen. Municipal sewage treatment plants appear to be important contributors to the hypoxic conditions that cause fish kills;

industrial dischargers too are important, though apparently to a lesser extent. Waste disposal contributes large quantities of nutrients to the Chesapeake Bay, although the precise magnitude of their contribution to the fish kills is unknown.[57] The extent and severity of fish kills appear to have been reduced in many areas over the last ten to fifteen years, although available information does not permit an accurate characterization of the reduction.[58]

HIGH BODY-BURDENS OF CONTAMINANTS

SHELLFISH CONTAMINATION

For many years, the concentrations of coliform bacteria and natural marine biotoxins in shellfish have been periodically surveyed. This information is increasingly being supplemented with information from "biomonitoring" surveys, in which the concentrations of toxic chemicals (such as metals and organic chemicals) in shellfish are measured.

Since 1966, the periodic National Shellfish Register has provided an important indicator of the extent to which shellfish in U.S. waters are polluted with coliform bacteria. According to the most recent register, of the "productive" shellfish areas in the U.S., 58 percent are approved for harvest, with the balance subject to some level of restriction (See Table 1). Commercial harvests of shellfish from roughly a third (27-42 percent) of productive areas are limited because of actual or potential contamination. Restricted areas are most prevalent in the Gulf of Mexico and along the southern Atlantic coast; these two regions together account for over 80 percent of the harvest-limited productive shellfish areas in the nation.[59]

Although an overall national trend in shellfish contamination is not clearly discernable from the register alone, the register is sufficient, in combination with other evidence, to indicate that bacterial contamination is a significant problem nationwide.[60]

Trends vary from one specific body of water to the next. In some areas, such in the vicinity of Savannah, Georgia[61] or San Francisco Bay,[62] shellfish contamination by fecal coliform has fallen to the point where shellfishing areas have been reopened for the first time in decades.

However, in other regions -- particularly in rapidly developing areas such as the coastal portions of the Gulf of Mexico and southern Atlantic states -- the problem often is growing.[63] This results not only from point sources

Table 1.—Classification of Shellfish Growing Waters (thousands of acres)

Region and State	Productive						
		Harvest limited areas					
	Approved for harvest	Prohibited	Conditionally approved	Restricted	Percent of total productive waters approved	Nonshellfish/ nonproductive	Total
Northern Atlantic:							
Maine	936	87	13	10	89	0	1,046
New Hampshire	4	6	0	0	40	0	10
Massachusetts	255	41	1	5	84	500	802
Rhode Island	96	20	12	0	75	0	128
Connecticut	309	78	6	0	79	0	393
New York	828	192	1	0	81	0	1,021
New Jersey	236	118	20	21	60	0	395
Pennsylvania	0	0	0	0	—	6	6
Delaware	209	19	3	0	90	44	275
Maryland	1,369	64	0	0	96	97	1,530
Virginia	1,295	174	33	0	86	2	1,504
Subtotal	5,537	799	89	36	86	649	7,110
Southern Atlantic:							
North Carolina	1,755	370	0	0	83	0	2,125
South Carolina	200	72	9	0	71	0	281
Georgia	61	144	0	0	30	0	205
Florida	40	36	37	0	35	748	861
Subtotal	2,056	622	46	0	75	748	3,472
Gulf of Mexico:							
Florida	266	260	306	0	32	578	1,410
Alabama	74	103	195	0	20	2	374
Mississippi	123	96	171	0	32	0	390
Louisiana	0	31	3,462	0	—	0	3,493
Texas	1,310	358	0	0	79	2	1,670
Subtotal	1,773	848	4,134	0	26	582	7,337
West coast:							
California	2	263	12	1	1	248	526
Oregon	14	14	0	12	35	44	84
Washington	147	49	45	0	61	1,795	2,036
Subtotal	163	326	57	13	29	2,087	2,646
U.S. total	9,529	2,595	4,326	49	58	4,066	20,565

DEFINITIONS:

Productive: Any areas which are not classified "nonshellfish/nonproductive." At one time this category only contained areas which did or could produce shellfish (either naturally or aquaculturally) in quantities sufficient to justify commercial harvesting. As a result of changes in the classification system, however, there is an effort underway nationwide to classify all coastal waters within subcategories of this category; consequently, it includes areas which formerly were termed "nonshellfish/nonproductive."

Approved for harvest: Area surveyed and found free of hazardous concentrations of pathogenic organisms and/or pollution. Molluscan shellfish may be commercially harvested at any time.

Harvest limited:

a) *Conditionally approved:* Area surveyed and shellfish are found to meet "approved" area requirements for only part of the year. Molluscan shellfish may be harvested only during periods when pollutant levels are deemed acceptable. The area may be closed for the balance of the year because of high pollutant levels or because the shellfish control authorities have failed to establish that "approved" area standards are being met during that period; such failure may result from various factors, including cutbacks in funding of classification activities.

b) *Restricted:* Area surveyed and shellfish are found to be contaminated. Shellfish may be harvested but only can be marketed if they first are purified in a depuration facility or "relayed" to an approved area. In either case, the shellfish may be marketed once they are depurated (cleansed of pollutants).

c) *Prohibited:* Area surveyed and closed due to hazardous levels of contamination; or area has not been surveyed at all. Molluscan shellfish may not be commercially harvested at any time.

Nonshellfish/nonproductive: At one time, if areas were determined to be inaccessible, or did not or could not produce shellfish (either naturally or aquaculturally) in quantities sufficient to justify commercial harvesting, waters were classified into this category. As a result of changes in the classification system, however, acreage in this category is now being transferred into subcategories of the "Productive" category. At present the "Nonshellfish/nonproductive" category accounts for less than 20 percent of total classified acreage.

SOURCE: U.S. Department of Commerce, National Oceanic and Atmospheric Administration; and Department of Health and Human Services, Food and Drug Administration, *1985 National Shellfish Register of Classified Estuarine Waters* (Washington, DC: December 1985).

(primarily municipal sewage treatment plants and combined sewage overflows, and from growing numbers of recreational boats), but also from nonpoint sources (such as runoff and groundwater seepage from increasingly developed and often unsewered coastal areas).

In addition to contamination with fecal coliform bacteria, shellfish contamination with metals and organic chemicals has been surveyed by state and federal government programs.[64] These efforts have varied widely among programs and from year to year. In some areas -- usually in marine waters adjacent to or downstream from urban, industrial, or agricultural areas -- elevated levels of metals and organic chemicals are frequently present in shellfish. These concentrations sometimes are high enough to adversely affect the shellfish[65] and to threaten consuming organisms, including humans. In some cases this has prompted government warnings or restrictions on fishing or consumption.[66] The full national extent of contamination by metals and organic chemicals, and its consequences and trends, are not known.

California provides a useful illustration of some characteristics of the shellfish contamination problem, because it has a relatively good monitoring program and a variety of marine environments and pollution problems. Since 1977, the California State Mussel Watch has been monitoring toxic chemical concentrations in mussels placed at strategic locations in the state's coastal waters. Between 1977 and 1985, at least eight areas were identified where toxic pollutants -- including many metals and synthetic organic compounds such as PCB -- had contaminated mussels to very high levels (Table 2).[67]

FINFISH CONTAMINATION

Only a very limited number and variety of fish have been analyzed for specific pollutants. These data reveal that the level of measured contamination varies widely -- geographically, among species, among individuals, and even in

TABLE 2

Intensive or 'hot spot' investigations for potential regulatory action by water quality authorities in California marine estuarine waters, 1981–1984

Location	Pollutant	Current Status
Crescent City	Silver, Mercury	Source control study in sewage system revealed an unpermitted discharge of silver; terminated; study of the source(s) of mercury input continued.
Eureka	Silver	Source control study in sewage system revealed an unpermitted discharge of silver; terminated.
	PCP	Suspected unpermitted discharge from lumber mill operations; study continued.
Fort Bragg	PCB_{1248}	Suspected illegal disposal of electrical transformers; small amounts of PCB_{1248} found in one location; no definitive source found; no further action taken.
San Francisco Bay	Silver	Significant accumulation of silver in mussels and sediments from non-point sources; silver concentration declined significantly in 1984; no further study or action.
	pp'DDE	Low levels widely distributed throughout bay, characteristic of non-point source discharge; no further study or action.
Moss Landing Drainage	Toxaphene Endosulfan I	Suspected agricultural source(s) of diffuse nature and difficult to identify responsibility; no regulatory action at this time; study continued.
	pp'DDE	Increased concentration of DDE in recent years; suspected illegal use; no regulatory action; study continued.
Monterey	Silver	Decrease in silver in mussels coincided with the sewage discharge termination; no regulatory action; study terminated.
	Lead	Extremely high lead concentrations in mussels and sediments; area quarantined for consumption of shellfish; potential source located and partially removed; further study of source and monitoring continued.
Los Angeles/Long Beach Harbour	Lead	Source suspected to be non-point surface runoff; continued monitoring.
	Copper; Zinc	Source suspected to be maritime origin; continued study.
	pp'DDE	DDT compound input from Dominguez Channel or Los Angeles River from manufacturing facility; site designated for possible regulatory action; further study and monitoring.
	PCB_{1254}	No definitive pattern in harbor; study continued.
San Diego Harbour	PCB_{1254}	Concentration in mussels exceed public health standards for human consumption; highest concentrations in restricted channels and backwaters; no point source(s) located; study continued.
	Copper; Zinc	Input from ore-loading facility caused regulatory action; continued study.
	Silver	High concentration of silver in proximity to major wastewater outfall (Point Loma); further documentation of input required.

Source: Martin, Michael, "State Mussel Watch: Toxics Surveillance in California," Marine Pollution Bulletin, 16 (4): 140-146, 1985.

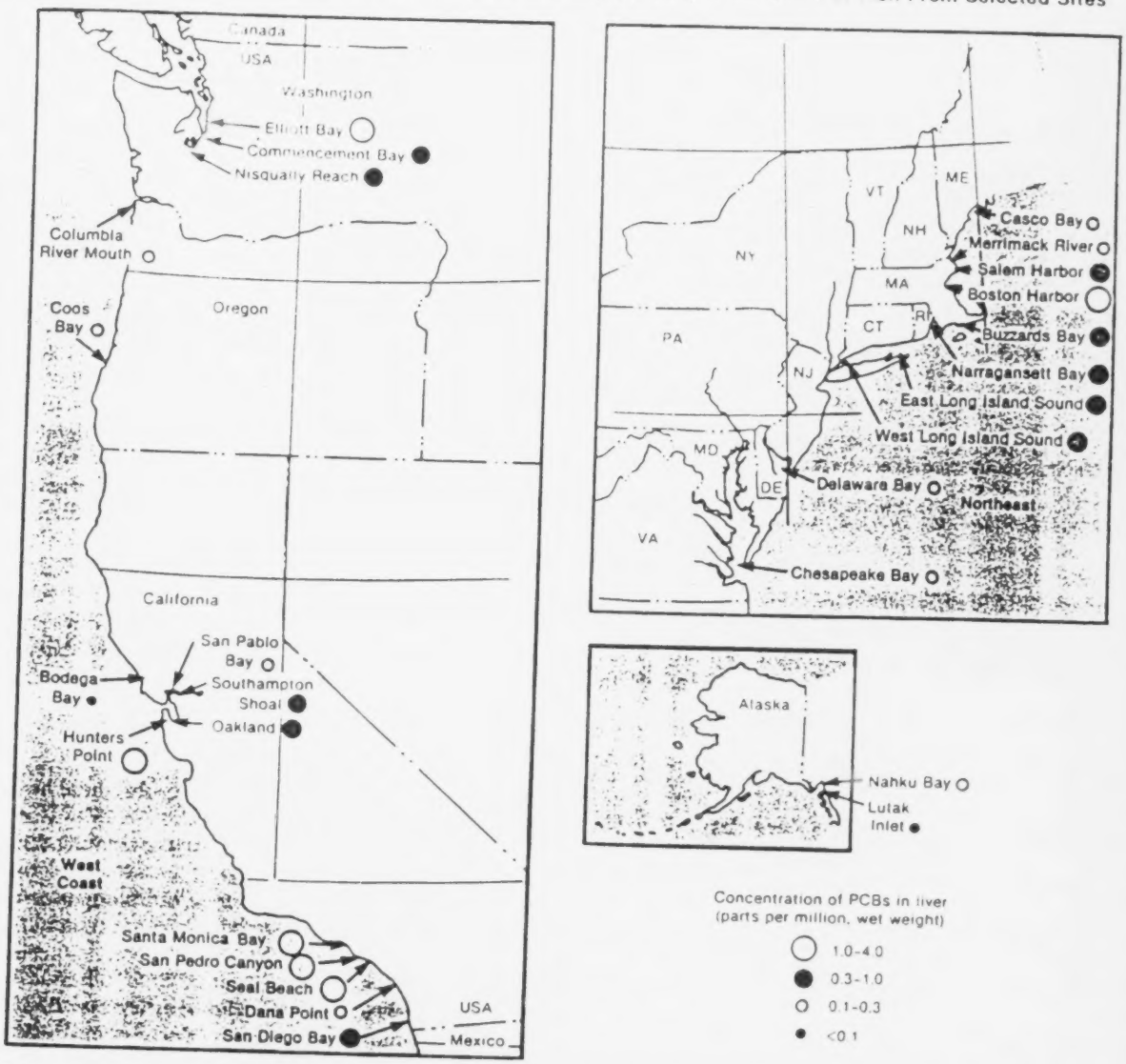
different tissues of a single contaminated specimen. Likewise, the origins of the contamination and its significance to the health of both humans and marine organisms varies. Finally, there are wide differences in trends; some pollutants are increasing in importance as others decline.[68]

Generally, contamination by metals and organic chemicals from point sources is most severe near urban and industrial centers, and in estuaries downstream from such areas (see Figure 7). Contamination has, however, been detected at distant points, in the open ocean; in those areas, very little information is available on the level of contamination and its consequences.[69]

Bottom-dwelling fish which spend a substantial portion of their lives in close proximity to polluted sediments appear to be most seriously exposed and contaminated, as are organisms at higher trophic levels. Sole and other bottom-dwelling fish have been contaminated with metals and organic chemicals in many areas of the country: Boston Harbor, Commencement Bay, Santa Monica Bay, and others. In most cases, pollutant levels do not pose a clear threat to the well-being of the fish or to consumers of such fish (other organisms or humans). The concentrations usually have been below the levels set by the FDA which require restricting consumption by humans -- in those instances where such levels have been established.[70]

There are, however, instances around the country where contamination levels have been sufficient to move officials to warn the public or even to restrict or prohibit the capture or sale of the fish. Many of the most serious and widely publicized problems have resulted from discharges of long-lasting chemicals (such as DDT and PCBs) that accumulate in the tissues of fish and are known to be toxic.[71] For example, the capture and sale of striped bass in New York has been banned because of PCB contamination, and signs have been posted warning against the consumption of fish caught in Santa Monica Bay in Southern California.

Figure 7.—Concentrations of Polychlorinated Biphenyls (PCBs) in the Livers of Fish From Selected Sites



The PCB concentrations found in the sampled areas generally are lower than those found to biologically affect freshwater or saltwater organisms. In some situations, however, biological effects have been detected at the PCB concentrations found at these sites. PCBs may cause reproductive failures, birth defects, tumors, liver disorders, and skin lesions, and they may suppress the immune system.

SOURCE: U.S. Department of Commerce, National Oceanic and Atmospheric Administration, Ocean Assessments Division, *Progress Report and Preliminary Assessment of the Findings of the 1984 Benthic Surveillance Project* (Rockville, MD: 1986).

OTHER EFFECTS ON FINFISH AND SHELLFISH

In addition to acute lethality and elevated body-burdens[72] of pollutants, exposure to pollutants or to environmental changes induced by pollutants may result in other changes in finfish and shellfish. Many effects are extremely difficult to document in the field; the extent and degree to which they occur often are unknown. Nevertheless, there is a growing body of evidence which links these effects to pollutants which sometimes are present at very low concentrations.[73] The effects are concentrated in estuaries and coastal waters, although detectable effects have been found in fish far from shore in the open ocean.[74]

Individual organisms may be affected in various ways; the effects may be negative, positive,[75] or inconsequential from the human standpoint. Some fish and shellfish will, if they can, avoid hypoxic bottom waters or waters containing various pollutants. Likewise, organisms living on or in sediments may avoid sediments which have been altered physically or chemically. Other aspects of their behavior may also change: for example, they may eat fewer or different organisms, be less active or grow more slowly.

Pollution also has been linked with physiological and biochemical changes and diseases in fish. These may range from subtle and relatively minor responses to physically visible and conspicuous pathological abnormalities. Most noticeable are effects such as fin erosion or fin rot, ulcers, shell disease or erosion, tumors, and skeletal anomalies. In some cases, resistance to infection has been lessened or reproduction or growth has been impaired. Some of these effects, although not immediately lethal, may eventually precipitate an organism's death.

These kinds of effects have been documented in polluted marine waters around the country. In Boston Harbor, for example, pollutants have been linked to fin erosion and cancerous lesions in winter flounder, a major commercial and recreational fish.[76] In San Francisco Bay, evidence suggests a linkage between pollutants and pathological problems -- including impaired reproduction -- in striped bass and Starry flounder.[77] In Puget Sound, various pathological conditions -- most notably liver tumors -- found in English sole and other fish are correlated with exposure to pollutants.[78] Numerous other examples have been documented, as well.[79]

In localized areas and over limited periods of time, the abundance, distribution, and/or diversity of some fish and shellfish have been affected by the disposal of wastes.[80] These changes most frequently result from pollution-induced changes in various closely interrelated ecological parameters -- food supplies, water quality, and habitat. For example, pulp mill effluents discharged into the Fenholloway River estuary, located along Florida's Gulf Coast, appear to be significant contributors to the decline in the extent and productivity of the area's seagrasses and some other types of algae. Because those photosynthetic organisms are of central importance in the coastal ecosystem, their decline has had major repercussions on populations of other organisms including fish and on community structure.[81]

On longer time-scales and over larger areas, however, evidence is rarely sufficient to conclusively establish cause and effect relationships between changes in fish populations and waste disposal activities. Nor is evidence usually adequate to detect trends. Despite this, considerable evidence, much of it circumstantial, indicates that pollutants from waste disposal activities have contributed to declines of major fish populations in the United States.[82] For example, many surveyed officials in eight southeastern states (along both the Gulf and Atlantic coasts) believe that widespread declines of anadromous species

(migratory species which spend portions of their lives in both fresh and salt water) in those states have been caused in part by pollutant discharges (See Table 3).[83]

SUBMERGED AQUATIC VEGETATION[84]

Substantial impacts on submerged aquatic vegetation (SAV) have been linked, with varying degrees of certainty, to waste disposal activities in many areas of the country. This is particularly important in view of the vital significance of SAV in marine ecosystems; it provides shelter and food sources, and performs other important ecological functions such as stabilizing sediments. During the course of the century, the general trend has been towards decreases in the areal extent of SAV, with some reversals during the last ten or fifteen years. A major cause of these declines is increased turbidity resulting from discharges of suspended solids or from growing populations of plankton fostered by releases of nutrients.

Examples exist around the country. In Florida, for example, significant losses have been noted in seagrass meadows (See Table 4); indeed, seagrasses in some areas have been virtually wiped out since 1940. The outlook for remaining seagrass beds in Florida is bleak.[85] Outside of Florida, perhaps the best known example is the Chesapeake Bay, where the SAV has declined precipitously over the last 15 to 20 years.[86] Studies indicate that a primary cause of the change has been increased eutrophication and associated turbidity, resulting in part from municipal and industrial discharges of nutrients. The decline of the vegetation has been paralleled by a decline in the abundance of winter migratory waterfowl that feed on SAV and in the numbers of striped bass.[87]

Another example exists off the coast of Southern California, where discharges from some municipal outfalls have been linked to impacts on the area's kelp forests. The precise mechanisms by which the pollutants have

TABLE 3

Factors Possibly Important in Contributing to the Decline of Certain Populations of Anadromous Fish in Coastal Waters of South Atlantic and Gulf States.

RIVER SYSTEM	NONE OR INADEQUATE INFORMATION	CHANNELIZATION	DREDGE AND FILL PROJECTS	BULKHEADING	DAMS AND IMPOUNDMENTS	INDUSTRIAL WATER INTAKES	INDUSTRIAL DISCHARGE LOCATIONS	ROAD CONSTRUCTION	ACID RAIN	CHEMICAL POLLUTION (eg. heavy metals)	THERMAL EFFLUENTS	TURBIDITY	LOW OXYGEN LEVELS	SEWERAGE OUTFALLS	INADEQUATE FISHWAY FACILITIES	POOR CONTROL OF WATER RELEASE (dams)	REDUCED FRESHWATER TO ESTUARIES	REDUCED SPAWNING HABITAT	REDUCED NURSERY HABITAT	POOR FOOD AVAILABILITY	SPAWNING GROUNDS TOO ACCESSIBLE	GENERALLY POOR WATER QUALITY	OTHER (See footnotes)
NORTH CAROLINA																							
Currituck So.	X																						
Albemarle So.													X									X	
Chowan		X	X	X		X	X			X		X	X	X			X	X	X	X	X	X	
Roanoke		X	X		X	X	X			X		X	X	X	X			X	X	X	X	X	
Pungo	X																						
Other Albemarle area rivers																						X	
Albemarle So. tributaries		X	X	X						X			X	X				X	X	X	X	X	
Tar		X			X	X	X			X		X	X	X	X			X	X	X	X	X	
Pamlico	X																	X	X	X	X	X	
Neuse		X			X	X	X			X		X	X	X	X	X		X	X	X	X	X	X[1]
Trent	X																						
North	X																						
Newport	X																						
White Oak	X																						
New		X																X	X				
Cape Fear		X			X	X	X			X		X	X	X	X	X		X	X	X	X	X	X[1]
N.E. Cape Fear		X								X		X	X	X				X	X	X	X	X	
Pee Dee					X	X	X			X		X	X	X	X							X	
SOUTH CAROLINA																							
Waccamaw	X																						
Pee Dee					X											X		X	X				
Black	X																						
Sampit										X												X	
Santee					X										X			X	X				
Cooper					X													X	X				
Ashley	X																						
Edisto	X																						
Ashepoo	X																						
Combahee	X																						
Lynches	X																						
Savannah					X										X			X	X			X	
GEORGIA																							
Savannah			X		X		X			X								X	X	X		X	
Ogeechee		X	X		X		X											X	X	X		X	
Altamaha		X	X		X		X			X								X	X	X		X	
Satilla		X	X		X		X											X	X	X		X	
St. Marys			X		X		X											X	X	X		X	
Apalachicola					X													X					

RIVER SYSTEM	NONE OR INADEQUATE INFORMATION	CHANNELIZATION	DREDGE AND FILL PROJECTS	BULKHEADING	DAMS AND IMPOUNDMENTS	INDUSTRIAL WATER INTAKES	INDUSTRIAL DISCHARGE LOCATIONS	ROAD CONSTRUCTION	ACID RAIN	CHEMICAL POLLUTION (eg. heavy metals)	THERMAL EFFLUENTS	TURBIDITY	LOW OXYGEN LEVELS	SEWERAGE OUTFALLS	INADEQUATE FISHWAY FACILITIES	POOR CONTROL OF WATER RELEASE (dams)	REDUCED FRESHWATER TO ESTUARIES	REDUCED SPAWNING HABITAT	REDUCED NURSERY HABITAT	POOR FOOD AVAILABILITY	SPAWNING GROUNDS TOO ACCESSIBLE	GENERALLY POOR WATER QUALITY	OTHER (See footnotes)
FLORIDA (Atlantic coast)																							
St. Marys		X		X		X	X			X									X			X	
Nassau				X		X	X			X									X			X	
St. Johns		X	X	X	X	X	X			X	X		X	X		X	X	X	X		X	X	X^2
Tomoka										X												X	X^3
FLORIDA (Gulf coast)																							
Hillsborough					X		X													X	X	X	X^4
Suwannee							X																X^5
Ocklockonee	X																						
Apalachicola		X	X	X	X		X			X		X		X	X				X	X		X	X^6
ALABAMA																							
Perdido							X			X			X									X	
Alabama					X	X				X			X		X	X			X	X		X	
Tennessee					X	X				X				X	X	X			X	X			
Tombigbee						X				X		X		X	X	X			X	X			
Coosa						X				X				X	X	X			X	X		X	
Tallapoosa						X				X				X	X	X			X	X		X	
Fish	X																						
Magnolia	X																						
Bon Secour							X																
Dog	X																						
Fowl	X																						
MISSISSIPPI																							
Pascagoula	X																						
Tchouticabouffa	X																						
Biloxi	X																						
Wolf	X																						
Jourdan	X																						
Pearl	X																						
LOUISIANA																							
Pearl		X		X																			
Bayou LaCombe		X		X																			
Tchefuncte		X																					
Tangipahoa		X																					
Tickfaw		X																					
Amite		X																					
Mississippi		X	X																				
Vermillion	X																						
Mermentau		X	X		X																		
Calcasieu	X																						
Sabine	X																						
Atchafalaya		X	X																				

[1] Locks and barriers

[2] Agricultural drainage; agricultural and domestic non-point source pollution; overfishing

[3] Agricultural and domestic non-point source pollution

[4] Agricultural and domestic non-point source pollutants; overfishing; proposed phosphate strip-mining

[5] Agricultural and domestic non-point source pollutants; proposed phosphate strip-mining

[6] Overfishing

Source: Rulifson, R.A. and Huish, M.T. and Thoesen, R.W., "Status of Anadromous Fishes in Southeastern U.S. Estuaries," p 413-425 in Kennedy, Victor S. (ed), Estuarine Comparisons (NY: Academic Press, 1982).

TABLE 4

LIST OF DATA CONCERNING HISTORIC ANTHROPOGENOUS IMPACT ON SEAGRASS MEADOWS IN FLORIDA

Study Area	Location	Status of Seagrass Meadows	Information Source
Indian River	Southeast Florida Atlantic Ocean	Historic declines in number and coverage of seagrass meadows. Declines in Vero Beach area, Fort Pierce Inlet (26%) and Sebastian Inlet (38%) from 1961 through 1984.	Gunderson and Gunderson, 1976; Florida Department of Natural Resources, unpublished data
Biscayne Bay	Southeast Florida Atlantic Ocean	Undetermined deterioration in northern Biscayne Bay. Some damage to *Thalassia-Halodule* beds near power plant (heated effluents) in south Biscayne Bay. Card Sound unaffected by power plant discharge.	McNulty, 1961; Roessler and Zieman, 1969; Thorhaug et al., 1973; Zieman 1970, 1982
Florida Keys	South Florida Atlantic Ocean	Few data found. Little effect of Key West desalination plant.	Chesher, 1971
Florida Bay	South Florida	Postulated altered species relationships due to increased salinity caused by redirection of freshwater runoff.	Zieman, 1982
Tampa Bay system	Southwest Florida Gulf of Mexico	Almost forty percent reduction in Boca Ciega Bay due to dredging, filling, and associated activity from 1950 through 1968. Multiple sources (urbanization, storm water runoff, sewage discharge, industrialization, toxic substances). Reduction of seagrass meadows in Tampa Bay system from 30,970 ha to 8,750 ha.	Lewis and Phillips, 1980; Simon, 1974; Lewis et al., 1985; Taylor and Saloman 1968
Charlotte Harbor	Southwest Florida Gulf of Mexico	Decline of 29 percent of seagrass beds from 1943 through 1984.	Harris et al., 1983
Pensacola Bay system	Northwest Florida Gulf of Mexico	Complete loss of seagrass beds in Escambia Bay, East Bay, and Pensacola Bay from 1949-1979. Some fresh-brackish water species extant in delta areas. Some *Thalassia-Halodule* beds still alive in Santa Rosa Sound. Losses due to urbanization, industrial waste discharge, dredging and filling, cultural eutrophication.	Livingston, 1979; Livingston et al., 1977; Olinger et al., 1975
Choctawhatchee Bay	Northwest Florida Gulf of Mexico	Historical deterioration of seagrass beds from 1949 through 1983. Causes unknown.	Burch, 1983
St. Andrews Bay	Northwest Florida Gulf of Mexico	No data found: Presumed impact due to urbanization, industrialization	
St. Joseph Bay	Northwest Florida Gulf of Mexico	Extensive coverage unchanged from 1972 through 1983. Relatively unpopulated area.	McNulty et al., 1972; Savastano et al. 1984
Apalachicola Bay system	North Florida Gulf of Mexico	Generally healthy assemblages of seagrasses. Local impact due to dredged opening in associated barrier island. Introduced species spreading in delta areas with as yet undetermined impact. Area under increased pressure from urbanization.	Livingston, 1980c, 1984
Apalachee Bay	North Florida Gulf of Mexico	Impacts due to disposal of pulp mill wastes (Fenholloway estuary) from 1954 to the present. Slow recovery noted in outer portions of impact area (associated with pollution abatement program). Area now threatened by proposed inshore navigation channel and possible offshore oil drilling operations.	Heck, 1976; Hooks et al., 1976; Livingston, 1975, 1982a, 1984a; Zimmerman and Livingston, 1976a, b

Source: Livingston, Robert J., Historic Trends of Human Impacts on Seagrass Meadows in Florida (St Petersburg, Florida: State of Florida, State Department of Natural Resources, Bureau of Marine Research, unpublished manuscript, dtd 1 Aug 1986).

affected the forest have not been clear, but they may involve increased sedimentation, water turbidity (resulting from higher concentrations of suspended solids), and toxic substances. Figure 8 shows a strong relationship between solids discharged by one municipal outfall and the acreage of kelp forest in the area. Reductions in the discharge of solids since 1970, accompanied by kelp restoration efforts, have been accompanied by increases in the kelp forest acreage.[88]

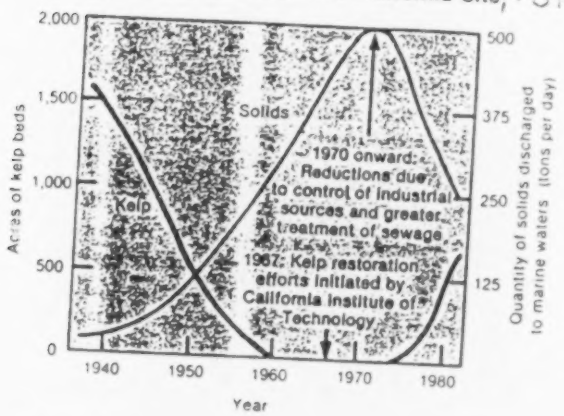
BENTHIC ORGANISMS

Changes in sediment or water quality induced by waste disposal frequently affect benthic plants and animals, those living on or near the bottom. Included among benthic organisms are many of the fish, shellfish, and vegetation discussed above. Benthic communities have been affected by waste disposal in every region of the country, though impacts tend to be most severe and extensive in the estuaries and coastal areas of the Northeast. The impacts are most severe in and near estuaries of pollutant-bearing rivers, near developed coastal areas, and near dredged material disposal areas.

Benthic organisms have been particularly exposed to such consequences of waste disposal as sediment contamination, hypoxic bottom waters, and increased turbidity, as well as physical changes in the sediment resulting from the settling of solids such as dredged materials. The effects on benthic organisms vary from relatively rapid death to subtle effects on species diversity and numbers, and from long-term and permanent to short-term and transitory.

For example, one study examined the consequences of the disposal of fine-grained dredged material at a location in the Chesapeake Bay. Many organisms were buried and consequently killed. But within 15 months, the area apparently had recovered completely.[89] Conversely, far more serious impacts have been observed in the New York Bight. Among the effects caused at least in part by

Figure 3 —Relationship Between Size of Kelp Beds and Quantity of Solids From Municipal Discharges at a Southern California Site, 1937-1981



These kelp beds are located near Palos Verdes, California; discharges are from the Joint Water Pollution Control Plant, operated by the Los Angeles County Sanitation Districts.

SOURCE: After J.C. Meistrell and D.E. Montagne, "Waste Disposal in Southern California and its Effects on the Rocky Subtidal Habitat," *The Effects of Waste Disposal on Kelp Communities*, W. Bascom (ed.) (La Jolla, CA: University of California Institute of Marine Resources, 1963).

waste disposal have been mass mortalities of benthic organisms, large scale and long term contamination, diseases and abnormalities, changes in abundance and distribution of particular species, and changes in community structure.[90]

As is the case with other organisms, trends pertaining to waste disposal impacts on benthic communities vary from place to place. In some areas, improvements have been noted since the early 1970s. Such, for example, has been the case on the coastal shelf of Palos Verdes, California, between 1971 and 1981. There, reductions in the emissions of pollutants such as suspended solids, DDT and PCBs, resulted in a reduction in the areal extent of the observed benthic impacts associated with two large ocean outfalls.[91] On the other hand, continued deterioration is observed elsewhere; this is the situation in the areas mentioned earlier in this chapter where shellfish contamination is increasingly prevalent.

GEOGRAPHICAL VARIATIONS IN IMPACTS

The extent of impacts on marine resources that are caused by waste disposal activities varies considerably among different waterbodies. The following sections briefly describe the physical characteristics, degree of development, and types and extent of impacts that are exhibited in different areas of the country (See Figure 9).

PACIFIC: NORTHWEST[92]

This region includes the marine resources off the coasts of Alaska, Washington and Oregon. Its coastline -- most of which is in Alaska -- is longer than that of any other region. The region also contains greater stretches of relatively enclosed bodies of water (such as estuaries, bays, and sounds) than any other region; again, most are in Alaska. Much of the region, with some notable exceptions, appears to be relatively free of conspicuous and serious marine impacts induced by permitted point-sources.

The major industrial development centers around the forest products industry and seafood processing; and to a lesser extent, mostly in Washington, metal processing. The municipal and industrial effluent discharged to the region's coastal waters originates primarily from two major areas: coastal areas around Puget Sound, and areas inland along the rivers, the most important of which is the Columbia River. The preponderence of information linking the disposal of municipal and industrial wastes and dredged material to marine environmental impacts centers on Puget Sound.

Outside of Puget Sound, waste disposal activities generally tend to be less concentrated and appear to cause less severe problems.[93] The available information mostly concerns impacts of pathogens on shellfish areas, of mill effluents and seafood processing plants on oxygen levels near outfalls, and of

Figure 9 .—The Five Coastal Regions of the United States Used in This Report

marine dumping--mostly dredged material--offshore of the Columbia River estuary. The impacts of these discharges appear to be highly localized, and poorly documented.[94]

PUGET SOUND

Puget Sound is a very large fjord in northwest Washington. The irregularly shaped sound contains many bays and inlets, which often tend to hold and trap pollutants. The sound supports important populations of fish, shellfish, birds and mammals. Shellfish and finfish caught commercially and recreationally in 1984 were valued at nearly $74 million.[95] The sound also is rich in bird life and marine mammals -- including harbor seals and even killer whales and other large marine mammals.[96]

The abundant wildlife, and interest and concern for the sound's natural resources, are reflected in the existence of numerous parks and wildlife refuges scattered along its shores. Its waters and shores annually attract 56 percent of the state's residents, and support a large tourism industry.[97]

In contrast to other areas in the Northwest, Puget Sound is characterized by a high degree of urban and industrial development, dominated by Seattle. With an unprecedented period of development beginning late in the 19th century came unparalleled waste discharges. When conditions were at their worst, large volumes of untreated wastes were released to the sound, with severe consequences -- such as toxic contamination of sediments -- which in some cases persist to this day.

Conditions in many respects have improved over the last 30 years, as some of the excesses of the past have been curbed. Nevertheless, in addition to urban runoff and other non-point sources, over 400 permitted point-sources discharge to the sound and continue to contribute significant quantities of pollutants.[98] Consequently, despite a reliance on and appreciation for the

sound's natural wealth, its natural resources in some instances continue to suffer with varying degrees of severity from exposure to presently discharged wastes and those released many years and even decades ago.

The impacts have been manifold (See, for example, Table 5).[99] Increasing areas of commercial shellfish beds have been closed because of fecal coliform contamination. In the case of Commencement Bay, levels of toxic pollutants are high enough to make it one of the most contaminated areas in the country and a "Superfund" site. Diseases and abnormalities, most notably liver tumors, have been detected in bottom-dwelling fish (See Table 6). These pathological conditions and other impacts have been linked with exposure to chemicals found in sediments, the water column, and food particles.[100] Concerns have been raised that the health of humans who consume large amounts of contaminated fish may be endangered.[101]

PACIFIC: CALIFORNIA AND HAWAII[102]

This area is distinguished from the other regions in that relatively more of its coast is open while less is enclosed in areas such as bays. Furthermore, its continental shelf is relatively narrow.

Relatively few impacts have been documented in Hawaii. In the State's many small estuaries, problems associated with waste disposal primarily result from the discharge of nutrients. These problems were greatly alleviated during the 1970s and early 1980s as sewage treatment plants were built and upgraded. In Kaneohe Bay, for example, sewage discharges in the 1960s and much of the 1970s seriously modified the natural communities of the area. In 1977 and 1978, most of the sewage was diverted to a deep ocean outfall. Conditions in the bay improved considerably, with notable reductions in turbidity and with a marked

Table 5

Selected Toxic Contaminants[1] in Puget Sound: Their Distribution, Sources, Effects, and Trends

	Water[2]	Sediment	Tissue	Sources	Effects	Trends
PAH	Detected at very low concentrations (.01 ppb) in waters of Puget Sound Central Basin. Mostly associated with particulates suspended in water.	Elevated concentrations (from 10x to 42x reference) in industrialized urban areas. Eagle Harbor has highest elevation measured.	Mainly in invertebrates, some in fish livers, rarely in fish muscle tissue. Elevated levels in invertebrates from Eagle Harbor, Mukilteo ferry dock area.	Variety of natural and anthropogenic sources including local fragment runoff from forest fire areas, automobile crankcase oil, crude oil and oil by products (such as creosote), and combustion of organic material. Present in municipal effluents, runoff, and some industrial effluents.	Potentially associated with altered benthic communities, sediment toxicity, and histopathological conditions in fin fish--no cause/effect relationships have been proven. Some PAH metabolites are carcinogenic and have been found in fish livers and bile.	In general, concentrations have declined since the 1950s, but distribution is highly dependent on proximity to source. Inputs will probably not vary considerably in near future due to variety of sources, although effects of population increase may cause increases.
PCBs	Detected at very low concentrations (.001 to .01 ppb) in waters of Puget Sound Central Basin. Mostly associated with particulates suspended in water.	Elevated concentrations (from 20x to 130x reference) in industrialized urban areas with exception of Bellingham Bay.	Found in nearly all organisms from nearly all areas; highest levels in fatty tissues of marine mammals with long lifespans (e.g., harbor seals from southern Puget Sound).	Coolant for electrical components such as transformers and capacitors now banned from production, but still in use. Can enter Puget Sound through runoff, spills, and illegal dumping.	Potentially associated with altered benthic communities, sediment toxicity, and reproductive failure in some marine mammals and birds--no cause/effect relationships have been proven. In California, PCB metabolites have been found in mussels, shrimp, and some fish livers. These metabolites have not been studied in Puget Sound.	Concentrations in most areas have decreased over time probably due to ban on manufacture. Barring wide-spread spills, dumping, or release from landfills, decrease should continue.
Copper	Detected at very low concentrations (.1 to 1 ppb) in waters of Puget Sound Central Basin.	Elevated concentrations (from 10x to 37x reference) in Elliott Bay, Hylebos Waterway, Everett Harbor, Bellingham Bay, Eagle Harbor and Sinclair Inlet. Highest elevation along Ruston-Point Defiance shoreline, Commencement Bay.	Copper can accumulate in tissues of bivalve mollusks, crustacea, fish livers, and birds in industrialized urban areas. Copper is a natural component of the blood of crabs, snails and some other invertebrates. Significant accumulation of copper in fish muscle tissue from several areas of Commencement Bay.	Principal source is probably municipal water supply pipes, also present in some industrial effluent, smelter slag, and as a component of some wood treatment, paint, and sand-blasting products.	Essential nutrient (especially for crustaceans) at low concentrations, can be acutely toxic at high concentrations. Potentially associated with altered benthic communities and sediment toxicity. No cause/effect relationships have been proven in Puget Sound.	Inputs have decreased due to water softening by city of Seattle, however, more copper pipe is coming into use as solid steel/zinc pipes are replaced. Inputs will likely remain fairly constant in the near future, dependent on effect of population increase and industrial developments.
Lead	Detected at very low concentrations (1 to 10 ppb) in waters of Puget Sound Central Basin.	Elevated concentrations (from 10x to 110x reference) in Elliott Bay and Sinclair Inlet. Highest elevation along Ruston-Point Defiance shoreline.	Lead can accumulate in tissues of bivalve mollusks, crustacea, fish livers, and birds in industrialized urban areas. Lead does not generally accumulate at high levels in fish muscle tissue.	A major source is lead in gasoline. Present in urban and highway runoff, some industrial effluent, and smelter slag.	Can be acutely toxic at high concentrations. Potentially associated with altered benthic communities and sediment toxicity. No cause/effect relationships have been proven in Puget Sound.	Inputs have decreased due to drastic reduction in lead content of gasoline. Observed concentrations will likely follow same trend through near future, but then follow trend in gasoline use.
Zinc	Detected at very low concentrations (1 to 10 ppb) in waters of Puget Sound Central Basin.	Elevated concentrations (from 10x to 43x reference) in Elliott Bay, Duwamish River, Ruston-Point Defiance (43x reference), Everett Harbor, Sinclair Inlet.	Zinc can accumulate in tissues of bivalve mollusks, crustacea, fish livers, and birds in industrialized urban areas. Zinc does not generally accumulate at high levels in fish muscle tissue.	Municipal water supply pipes, urban and highway runoff, some industrial activities (e.g., plating), and smelter slag.	Essential trace nutrient, can be acutely toxic at high concentrations. Potentially associated with altered benthic communities and sediment toxicity. No cause/effect relationships have been proven in Puget Sound.	Inputs have decreased due to water softening by city of Seattle and other municipalities, and replacement of steel/zinc pipes. Inputs will likely remain fairly constant in near future.
Mercury	Detected at very low concentrations (<.001 ppb) in waters of Puget Sound Central Basin.	Elevated concentrations (from 10x to 170x reference) in Elliott Bay, Ruston-Point Defiance (170x reference), Bellingham Bay, and Sinclair Inlet.	Historically high concentrations in mussels from Bellingham Bay. Mercury can accumulate in tissues of bivalve mollusks, crustacea, fish livers, and birds in industrialized urban areas. Mercury has not been found to accumulate at high levels in fish muscle tissue from Puget Sound, but does in fatty tissues of long-lived marine mammals (probably as methyl mercury).	Historically from chloro-alkal plants (e.g., Bellingham Bay). Also from other industrial/commercial services including smelter activities and some wood treatment products.	Acutely toxic to many marine organisms, in organo-metallic form, at high concentrations. Can bioconcentrate. Potentially associated with altered benthic communities and sediment toxicity. No cause/effect relationships have been proven in Puget Sound.	Concentrations in dogfish have declined since mid-1970s. Concentrations in surface sediment in Bellingham Bay have declined since 1970s.
Arsenic	Detected at very low concentrations (1 to 10 ppb) in waters of Puget Sound Central Basin.	Elevated concentrations (from 10x to 620x reference) in Hylebos Waterway and Ruston-Point Defiance (620x reference) shoreline.	Arsenic levels in invertebrates, fish, and birds from areas containing contaminated sediments are similar to those in reference areas. A naturally high level of arsenic in seawater in the Northeast Pacific and Puget Sound is a major source of arsenic in organisms.	Principal single source was ASARCO copper smelter. Also component in urban runoff, and some industrial effluent. The largest (mass-loading) sources of arsenic to Puget Sound are the Pacific Ocean, and Puget Sound area rivers, from the natural erosion of rocks and soils.	Acutely toxic to most marine organisms. Potentially associated with altered benthic communities and sediment toxicity. No cause/effect relationships have been proven in Puget Sound.	A major source (ASARCO) has been discontinued, concentrations in sediment and biota in vicinity of smelter should decrease in near future. Other concentrations will likely remain fairly constant, except may also decrease as controls are implemented on runoff from areas using slag or ballast.

[1] These toxic contaminants are selected because they have been the most studied. Many other toxic compounds are known to be present in harmful amounts.

[2] From Romberg et al., 1984.

Source: Puget Sound Water Quality Authority, The State of the Sound 1986 (Seattle, WA: Puget Sound Water Quality Authority, 1986).

-PAGE 254-

TABLE 6

Pathological conditions in English sole from the Duwamish River, a polluted estuary in Seattle, Wash., as compared to English sole from McAllister Creek, a reference ("clean") estuary 80 miles south of Seattle.

Abnormalities in English sole	Duwamish River		McAllister Creek	
	Number of fish examined	Frequency of abnormality (%)	Number of fish examined	Frequency of abnormality (%)
Liver tumors				
Adult only (1975)	62	32	37	0
Adult & juvenile (1978)	252	8	18	0
Fin erosion	476	2	71	0
Severe hepatocellular lipid accumulation	256	45	37	11
Gill hyperplasia	256	15	37	0

Source: McCain, B.B. and D.C. Malins (1979) Uptake, fate, and effects of aromatic hydrocarbons on selected fish and crustaceans from the Northeast Pacific Ocean. Presented at the Marine Ecosystems Analysis (MESA)-New York Bight meeting, held in New York, June 1979.

Source: Malins, Donald C., "Pollution of the Marine Environment," Environmental Science and Technology, 14 (1): 32-37, January 1980.

recovery in the bay's coral community. Some problems, however, remain in areas such as Pearl Harbor and Mamala Bay, where treated sewage from concentrated populations result in continued impacts.[103]

Most of the region's urban and industrial development, and the waste discharges, are in the state of California. Municipal wastes from the state's large and growing population are voluminous and contribute substantial quantities of many different types of pollutants. Industrial effluents, dominated in the coastal regions by the petroleum refining, metal finishing, and inorganic chemicals industries, also are sizeable. Runoff, particulary from cities and from the state's extensive agricultural areas, additionally is a major contributor to the pollutants entering coastal areas.

The region contains areas of widely varying environmental quality, ranging from relatively pristine waters to some of the most polluted waters and seriously affected marine resources in North America.[104] Two areas in particular suffer great environmental impacts from waste disposal activities -- the San Francisco Bay and the Southern California Coast. However, pollutant impacts also frequently occur in other localized areas.

SAN FRANCISCO BAY[105]

San Francisco Bay is a large and enclosed estuary. It is extremely shallow, surrounded mostly by low-lying mudflats and a few small beaches and marshes. The bay supports valued recreational and commercial fisheries, including many anadromous species. Harbor seals also are found throughout the bay. Large populations of birds frequent the area. Many birds use the bay as they migrate along the Pacific flyway; indeed, the bay provides the most important habitat on the California coast for shorebirds as they migrate from Arctic breeding grounds. Considerable numbers of migratory birds overwinter there.[106]

Along the bay's shores are numerous areas such as reserves and refuges where wildlife is specifically protected; and many recreation areas such as parks. The natural resources attract many millions to the area each year, for diverse activities ranging from simply enjoying the scenery to recreational fishing.[107]

Much of the bay is ringed by intense urban development, including San Francisco, Oakland and San Jose; industry, including major petroleum refineries, also is established in the area. The bay receives pollutants from these sources as well as relatively large quantities of pollutants carried by the rivers of the Central Valley. Pollutants, along with other factors, have altered the bay's ecosystem.

As early as the turn of the century, industrial wastes were linked to the collapse of the bay's oyster industry. Conditions continued to deteriorate for many decades, into the 1960s, when oxygen deficiencies periodically would kill massive numbers of fish. The shellfish industry by that time had been largely destroyed.

The situation <u>in some respects</u> has improved markedly since the early 1960s, due to a large extent to the reduction of pollutant loads resulting from the construction of waste treatement facilities. Fish kills no longer are a regular occurrence, and concentrations of pathogenic bacteria have fallen. Indeed, in 1982, shellfish harvesting was sanctioned in parts of the bay for the first time since 1930.

But serious problems persist, especially in the shallower and poorly flushed portions of the bay. Substantial volumes of pollutants continue to be discharged directly and indirectly to the bay.[108] Eutrophication and low concentrations of dissolved oxygen still are localized problems. Significant

portions of the biota are exposed to elevated concentrations of contaminants such as pathogens, trace metals, PCBs, and DDT. Impacts to benthic organisms, fish and birds have been and continue to be documented.[109]

SOUTHERN CALIFORNIA COASTAL WATERS

The coastline of southern California is relatively smooth, with many sandy beaches and wetlands. Rocky promontories occasionally break the shoreline; islets and a few large islands rise offshore. The area's waters support a wealth of sealife. Prominent are the giant kelp beds along much of the coast; these provide an important habitat for many species and support a substantial kelp harvesting industry. Valuable fish and shellfish are found here. Marine mammals also are present; many breed in the area. Birds too inhabit the area; some are resident all year around, while others simply stop by or spend the winter as they migrate along Pacific Flyway.[110]

The marine waters are of considerable value to humans. This is evidenced by extensive commercial and recreational fisheries and kelp-harvesting operations; and by the numerous areas such as beaches, refuges and sanctuaries. Juxtaposed to the waters and their resources is one of the great urban concentrations of the continent, from which large volumes of wastes are discharged to the marine waters, primarily through outfalls. Pollutants in these discharges have affected the environment in several ways.

Elevated concentrations of many pollutants have been observed in the water, sediments and biota. Fecal coliform bacteria reach high concentrations near the outfalls, but do not appear to cause problems along the shore;[111] serious problems with fecal coliform bacteria are confined primarily to the area near the Mexican border, where high concentrations originating from Mexico have compelled the closure of U.S. beaches and restrictions on shellfishing.[112] [113]

Elevated concentrations of chlorinated hydrocarbons and metals also have been detected in sediments and in various marine organisms (See Figure 10).[114] Prominent among these are DDT and related compounds which in some areas and some organisms reach very high concentrations, largely as a result of disposal of wastes by a DDT-manufacturing plant. Most of the DDT was discharged prior to 1970, though its impacts persist to this day.[115] High concentrations of DDT, its metabolites, and PCBs have been found in fish caught by local fishermen and sold in local fish markets;[116] in shellfish sampled as part of California's Mussel Watch monitoring program; and in the blood of recreational fishermen.[117]

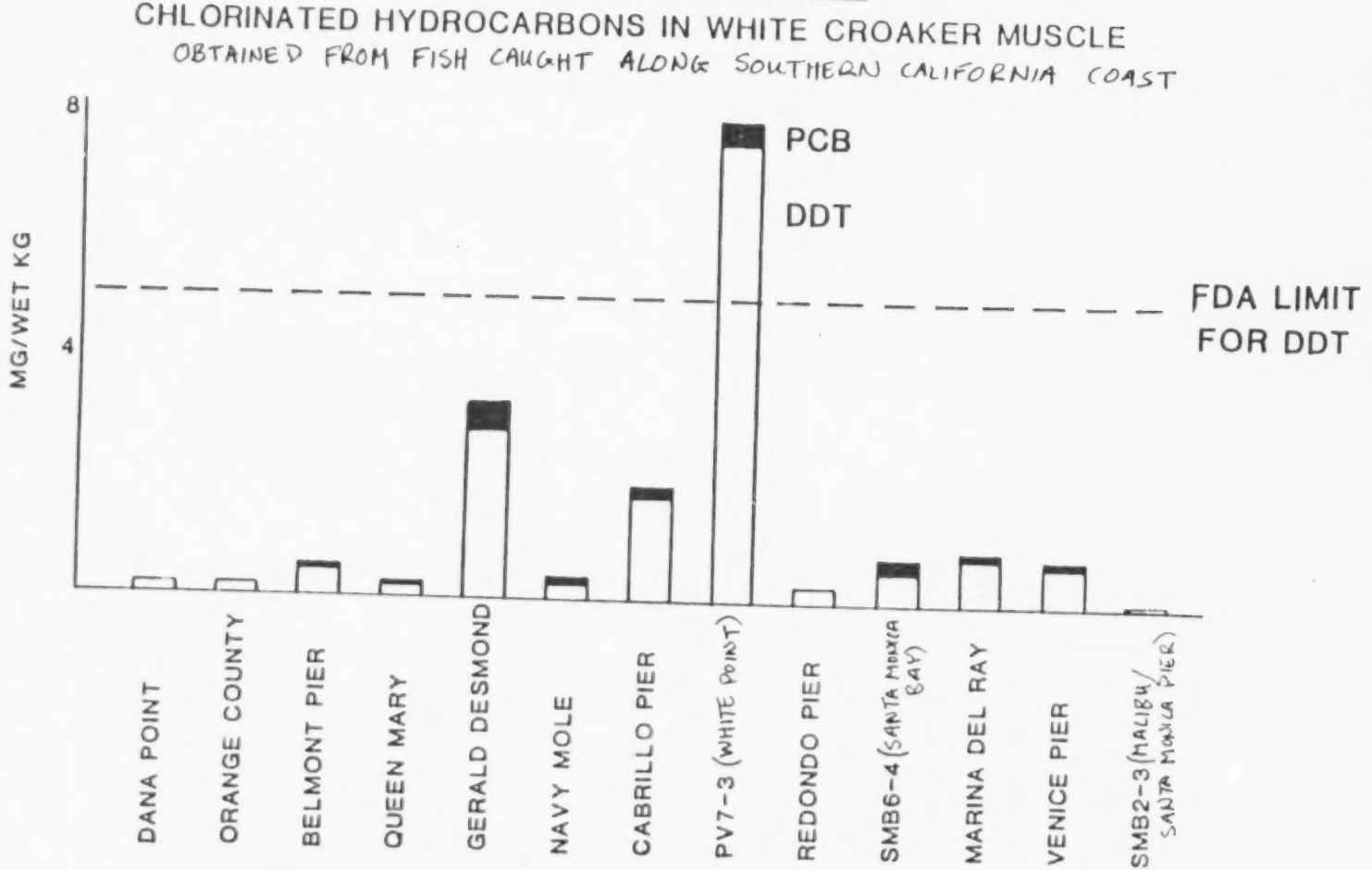
Of considerable recent concern has been the human consumption of contaminated fish and shellfish. Apprehension over human exposure to these pollutants, especially DDT and its metabolites, has resulted in the prohibition of commercial fishing around specific outfalls. Some guidelines to reduce ingestion of contaminated fish have been established, and signs have been posted warning against consumption of fish caught in Santa Monica Bay.[118]

In addition to elevated concentrations of contaminants in organisms, other impacts have been documented on shellfish, finfish, birds, mammals, and aquatic vegetation.[119] Among the consequences detected in fish and linked to pollutants are liver abnormalities, fin erosion disease, and reproductive problems.[120] Perhaps the most common impact is on benthic communities around several outfalls. For example, the benthos around three of the area's major outfalls was found in 1984 to have been changed or degraded over an area of 108 square kilometers (km^2). This is a substantial area, though it is a significant improvement over the 163 km^2 square kilometers (5 percent of the mainland shelf) which were changed or degraded in 1977.[121]

As is the case elsewhere in the country, trends in Southern California during the 1970s and early 1980s were mixed, though often were for the better as emission controls were tightened. As mentioned above, the area over which the

FIGURE 10

Chlorinated Hydrocarbons in White Croaker Muscle from the Southern California Bight.



Source: Brown, David A., Risk Assessment Applied to Southern California Coastal Fish (Long Beach, CA: Southern California Coastal Water Research Project, May 1, 1985), photocopy.

benthos is degraded near several major outfalls has declined with improved sewage treatment. Figure 8, in the earlier section on submerged aquatic vegetation, illustrates an increase in the areal coverage of kelp forests. Also, concentrations of DDT in many organisms and areas fell substantially after discharges of DDT were sharply reduced in the early 1970s (See Figure 11).[122] Other improvements have been noted along the coast as well.[123]

GULF OF MEXICO[124]

The Gulf of Mexico, with its extremely productive habitats and wealth of sea life, is one of the most productive and important marine areas of the United States.[125] It also receives large volumes of pollutants. By far the largest volume of many pollutants (from both point and non-point sources) is carried to the Gulf by the region's rivers, especially the Mississippi, from areas beyond the immediate coastal area.[126] The Mississippi, for example, carries wastes from areas extending from urban and rural areas deep in the nation's interior to the heavily developed stretch around Baton Rouge and New Orleans.

Though small relative to the quantities of riverborne pollutants, considerable volumes of waste are discharged in the form of municipal and industrial wastes from within coastal counties; large volumes of dredged material also are dumped in the region's marine waters. The major industrial discharges along the coast are associated with refineries and the petrochemical industry, especially in Louisiana and Texas; and with the forest products and seafood processing industries throughout the Gulf coast. Despite the overall dominance of riverborne pollutants, in many areas these local sources substantially affect the quality of the marine environment.

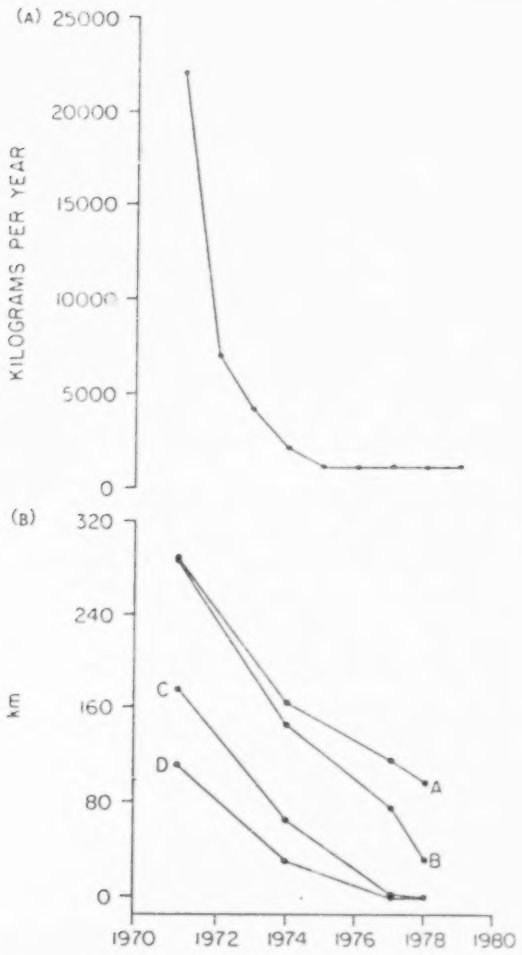


Figure 11. (a) Annual change in total DDT mass emission rate from major Southern California ocean outfalls, 1971 through 1979. Decline was due principally to source control initiated in late 1970 by Los Angeles County Sanitation Districts. Data are from compilation by the Southern California Coastal Water Research Project (see Schafer 1980). (b) Changes in length of coastline bearing mussels contaminated by DDE, 1971 through 1978. Four levels of contamination, in μg/kg dry weight (ppb) are (A) ≥50, (B) ≥100, (C) ≥500, and (D) ≥1000. Coastline lengths were interpolated from data in Figure 1 (b).

Source: Mearns, Alan J. and O'Connor, Thomas P., "Biological Effects Versus Pollutant Inputs: The Scale of Things," p 693-722 in White, H.H. (ed), Concepts in Marine Pollution Measurements (College Park, MD: University of Maryland Sea Grant, 1984), p 698.

Wastes from disposal activities have been linked to various ecological impacts. Dissolved oxygen levels are depressed and eutrophication is common in areas close to shore.[127] Extensive hypoxia also has been documented in the waters further offshore, south of Louisiana (see Box 1), but the degree to which waste disposal contributes to the phenomenon has not been ascertained.

The second major problem is the contamination of waters with human fecal coliform. This problem exists in virtually every coastal state in the Gulf and appears to result primarily from nonpoint sources (e.g., contaminants from septic tanks, washed into estuaries and coastal waters by runoff); however, point sources, including municipal sewage plants, also contribute to the problem in some areas.

Other problems, often less evident, result from releases of metals, chlorinated hydrocarbons, and other chemicals. The impacts usually are localized, and they can be quite serious in highly developed areas and in waters where circulation is relatively poor -- for example, in parts of the Mississippi Sound (See Box 2) or Galveston Bay. Other affected areas occur throughout the Gulf.[128]

Several impacts to marine organisms have been linked to the above pollutant discharges. Many of the region's shellfish beds are contaminated with fecal coliform bacteria.[129] Abnormalities which may be pollution-related have been found in some of the region's fish and shellfish.[130] Vital beds of seagrasses have declined throughout the region.[131] Declines in populations of fish and shellfish have been noted in some areas,[132] and birds have been found with elevated levels of contaminants -- sometimes at levels which may impair reproduction.[133] A variety of ecological changes, manifested as changes in the abundance and distribution of particular organisms, have been noted in some areas and linked to waste disposal activities.[134]

BOX 2: ENVIRONMENTAL STRESS IN THE MISSISSIPPI SOUND

Mississippi Sound is a long shallow embayment which stretches along the south end of Mississippi, overlapping somewhat into Alabama and Louisiana. Its northern limits are characterized by marshes, bayous, rivers and small bays; to the south it is bordered by series of islands. The area is extremely productive of marine life and is considered one of the most valuable fisheries nursery grounds of the world.[1]

Reflective of this is the area's large commercial fishing industry. The magnitude of the landings in Mississippi ports in 1985 was over 470 million pounds, ranking it as the fourth largest state in U.S. in terms of the weight of its landings. The landed value of these fish was over 40 million dollars. Landings in the Pascagoula-Moss Point area, dominated by menhaden and shrimp, are among the largest among gulf fishing ports.[2] Mississippi marine recreational fishery has been valued at nearly $45 million.[3] And coastal tourism generates an estimated $200 million each year.[4]

At the same time, the sound is bordered by some of the major urban and industrial centers of the Gulf of Mexico, including Biloxi-Gulfport and Pascagoula-Moss Point. Among the area's industries are petroleum refineries, petrochemical plants and pulp and paper establishments. Significant quantities of pollutants, from both point and non-point sources, for many years have entered the Gulf.

Especially serious problems associated with point sources are the discharge of nutrients and oxygen-demanding contaminants from both industrial and municipal sources. Also of considerable concern are discharges of pathogens from municipal sources, and of toxic contaminants from industrial sources. Evidence suggests linkages between these contaminants and diseases in fish and shellfish in portions of the sound.[5] Given the likelihood of continued rapid urban and industrial growth, there is considerable concern that the problems may become more severe.[6]

A recent study of pollutant transport in the Mississippi Sound[7] found that the concentrations of toxic pollutants in sediments tend to be extremely variable, with the highest concentrations frequently being in the rivers and bays close to the sources. These peripheral waters receive much of the contaminants, many of which associate with particulates and precipitate from the water column into the sediments near the point of release. Relatively little is discharged directly to the open sound.

An index of environmental stress was used to indicate the relative degree of potential impacts of the toxic pollutants on living resources of the Sound. The greatest toxic contamination problems are located in the Pascagoula River (See Figure 12) system and the Biloxi Bay areas. The most serious toxic pollutants -- and those which exhibited the widest variations in concentrations -- were hydrocarbons.

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[1]Ref. 38.

[2]Ref. 891A.

[3]Deegen, Fred and Herring, James R., Mississippi Sportsfishing Summary (Long Beach, Miss: Department of Wildlife Conservation, Bureau of Marine Resources, 1981), as quoted on p 1.1 of Ref. 388.

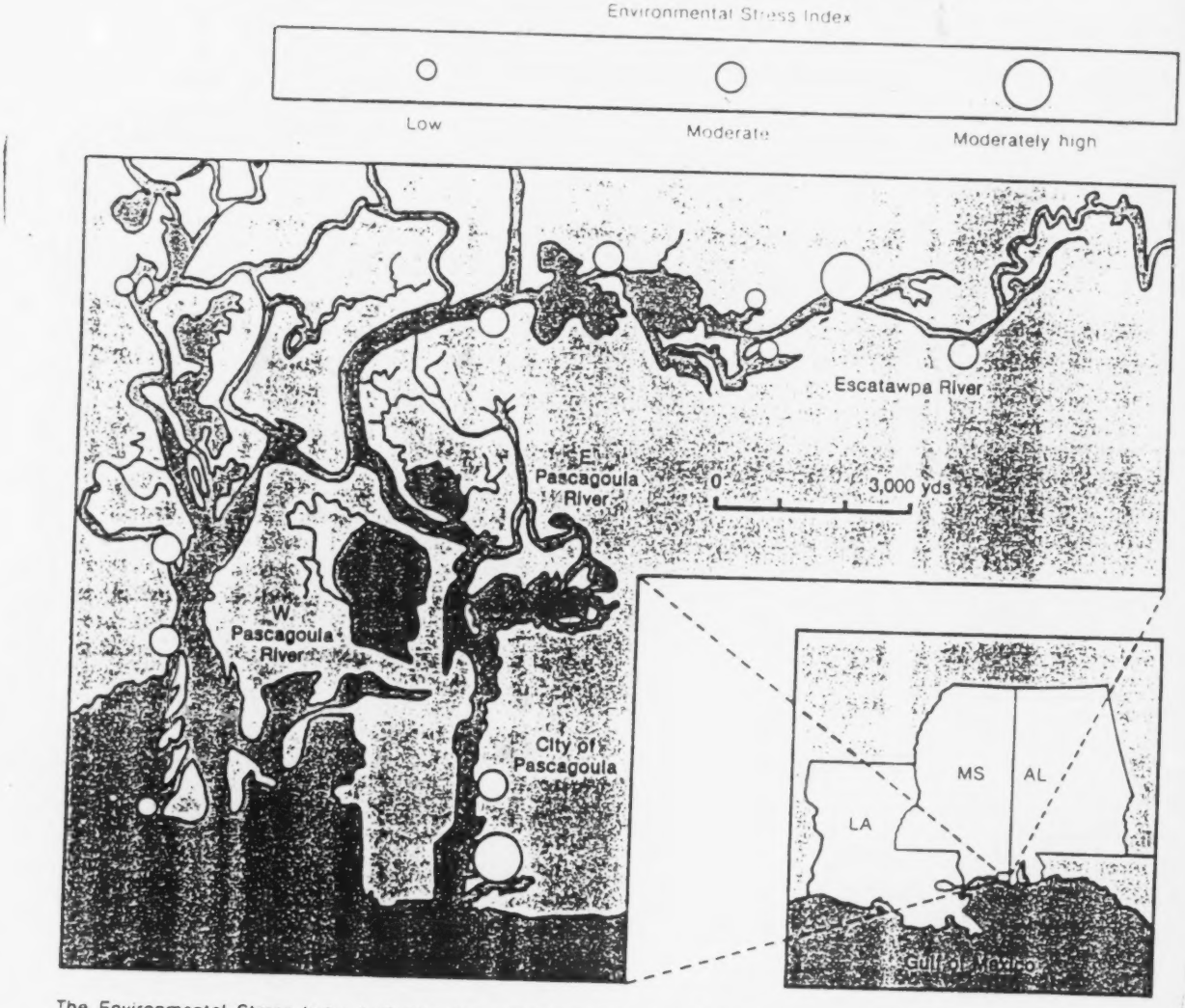
[4]United States Travel Data Center, The Economic Impact of Travel in Selected Mississippi Counties, 1978 (Washington, D.C.: United States Travel Data Center, 1980), as quoted on p 1-2 in Ref. 388.

[5]Ref. 599.

[6]Ref. 503

[7]Ref. 425.

Figure 12.—Environmental Stress in the Pascagoula Area of the Mississippi Sound



The Environmental Stress Index indicates the ecological risks associated with sediment contamination; a high value represents a higher risk of serious environmental stress. The index is a mathematical product of numerical ratings in four categories:

1. toxicity of sediments to selected organisms under laboratory conditions;
2. how readily sediment settles to the bottom after disturbance;
3. likelihood of sediment disturbance (e.g., from boat traffic or dredging); and
4. vulnerability of organisms to toxic substances (including factors such as ecological importance of indigenous species, life stages present, species diversity, mobility, and others).

SOURCE: Adapted from T.F. Lytle and J.S. Lytle, *Pollutant Transport in Mississippi Sound* (Ocean Springs, MS: Mississippi-Alabama Sea Grant Consortium, 1985).

Since the late 1960s and early 1970s, a significant reduction has occurred in some locations along the Gulf in the quantities of nutrients and oxygen-demanding substances released from municipal and industrial discharges. Reflecting this change, problems --such as major fish kills-- associated with low dissolved oxygen concentrations appear to have been alleviated in some instances.[135] Likewise, point source discharges of fecal coliform and in some metals and organic chemicals have been reduced in some areas.[136]

These and other pollutants nevertheless still pose severe and sometimes worsening problems parts of the region, in part because of extremely rapid population growth. Some observers are concerned that these may become still more serious as rapid urban and industrial development proceeds.[137] Also of concern is the possibility that dredging and impacts associated with dredged-material disposal, may increase dramatically with the creation of several deep-water ports.[138]

ATLANTIC: SOUTHERN STATES[139]

The southern Atlantic region (bordering the southeastern U.S. coast) is characterized by an irregular shoreline, with many bays, drowned river valleys, wetlands, and islands.[140] The Florida coast is most heavily developed, with several large cities, the largest of which is Miami; north of Florida, the coastal zone is lightly populated with the exception of several medium-sized cities.

Municipal waste discharges are concentrated along the relatively small portion of the coast that is densely populated, largely in Florida. Industrial effluent in the region is dominated by that from the forest products industry, scattered along the coast. Nonpoint sources are important and sometimes the predominant sources of pollution, contributing significant amounts of pollutants directly to marine waters, and indirectly through rivers and streams.

Waste disposal activities have contributed nutrients and fecal coliform bacteria to the area's coastal waters. In some cases, problems associated with point source releases of nutrients and fecal coliform have been alleviated over the last fifteen years as a result of federal and state pollution control legislation.[141] These gains have been offset to varying degrees elsewhere, however, by development -- sometimes very rapid development -- in coastal and inland areas that has resulted in growing releases of these same pollutants from both point and nonpoint sources.[142] In North Carolina, for example, between 1980 and 1985, the "approved" shellfishing areas declined by one percent, while the "prohibited" acreage increased by four percent.[143]

There is relatively little information on the concentrations of toxic pollutants in the marine waters and sediments of this region. The available information suggests that elevated concentrations, where they have been found, are in near-coastal areas with substantial urban or industrial development.

Areas with elevated concentrations of metals or hydrocarbons include parts of Florida such as Biscayne Bay and St John's River[144] and isolated areas in South Carolina[145] and North Carolina[146]. It frequently is not clear what the origin of the pollutants are; the relative importance of point sources varies from one instance to the next.

Very little is known of the trends in emissions and impacts of toxic pollutants in the region. Evidence suggests that reductions in the concentrations of metals and synthetic organic chemicals may have in some instances occurred during the 1970s and early 1980s.[147] In other waters, increases are evident.[148] For example, data suggests that contamination by toxic pollutants along one segment of the St. Johns River increased between 1970 and 1979.[149]

Pollutants have been linked to several types of impacts among the living organisms of the region. The nutrient discharges have contributed to eutrophic conditions and hypoxia,[150] which in turn have been linked to fish kills, depressed populations of certain benthic organisms, and declines in the extent of seagrass meadows.[151] Metals and synthetic organic chemicals have in some instances resulted in elevated concentrations of the pollutants in fish and shellfish. For instance, a recent study of fish from Florida's St. Johns River revealed that while mercury levels were below FDA limits, they were high enough to suggest the possibility of adverse health effect for a very small number of individuals.[152]

Pollutants also are believed to be partially responsible for the decline of some commercial and recreational fisheries, including those based on anadromous fish.[153] In North Carolina, for example, pollutants from point sources have been linked to the decline of commercial fisheries --including striped bass and herring -- over the last decade.[154]

Significant too are indications that pollutants may be partially responsible for outbreaks of disease among fish. Occurrence in the region of "red sore disease," caused by a type of bacterium, has been correlated strongly with eutrophic conditions. In addition, relatively high incidences of what has been termed "ulcerative dermal necrosis" have been observed among some of the region's fish.[155] From St. Johns River, Florida up to the Chesapeake Bay, several species of fish-- especially Atlantic menhaden--have been caught with deep red lesions on various parts of their bodies. No clear explanation has been found for the disorder. The precise nature of any linkage to pollutants, if it indeed exists, is largely a matter of speculation at this time.

One report, for example, found that among 106 menhaden caught in the St. Johns River by a fisherman, 100 had lesions of varying degrees of severity. Some samples contained high concentrations of heavy metals and petroleum hydrocarbons. The authors reported however, that "no inference is being made that these are the substances responsible for the current status of the fish..." They add that:

> "Such inferences would be scientifically unsound based on both the limited numbers and types of samples analyzed and the fact that excessively high levels of certain pollutants may easily mask a trace component of considerably higher toxicity. It is also highly likely that the present problem is due to a combination of factors."[156]

THE PAMLICO-ALBERMARLE ESTUARINE COMPLEX[157]

The Pamlico-Albermarle estuarine complex is a coastal lagoon containing six sounds, of which the Pamlico and Albermarle Sounds are the largest. The complex is located in North Carolina, immediately south of the border with Virginia. It is separated from the open ocean by a series of barrier islands. The complex's irregular shoreline include the estuaries of several major rivers

and many smaller streams which drain not only substantial portions of North Carolina, but small portions of Virginia too. The area is the third largest complex of estuaries in North America.

Seagrass beds are extensive, as are marshlands. Many species of fish, of both commercial and recreational importance, are found here; among these are striped bass, a species threatened by pollution in other parts of the country. For numerous organisms, the complex provides critical nurseries where shelter and food can be found for young fish and shellfish. The area also provides an important habitat for overwintering migratory waterfowl.[158]

Given the ecological preeminence of the estuarine complex, the present and anticipated pollution loadings and impacts are grounds for great concern. The area, relative to waterbodies to the north such as Chesapeake Bay, has in the past been less developed; sizeable tracts of undeveloped land exist along the sounds and further up in their watersheds. These conditions are changing relatively rapidly, however, as larger areas are farmed and as communities are established and expand; threats to the area's marine resources are growing and likely will continue to grow.[159]

In many instances, waste disposal activities are significant contributors to nutrient loads;[160] but large quantities of nutrients usually are coming as well from other sources, primarily runoff from farms and logging areas. Point sources are dominated by the forest products and phosphate mining industries. Municipalities also discharge significant volumes of sewage to the coastal waters.

The most serious impacts, from both point and non-point sources, have resulted from the discharge of nutrients. Most significantly affected are the lower Chowan river estuary (leading into Albermarle Sound); the upper Neuse

River and Pamlico River Estuaries, both of which lead into Pamlico Sound; and other localized areas on the fringes of Albemarle and Currituck Sounds in the northern part of the complex.

Several consequences of nutrient enrichment are evident in the area's waters. Hypoxia periodically occurs, accompanied by massive fish kills. "Nuisance blooms" of blue-green algae periodically are observed. These blooms appear to be substantially altering local food chains and reducing the abundance of the foods preferred by some species, including fish of considerable commercial or economic importance such as herring. The abundance of these fish species has declined in the affected areas, apparently as a consequence of these changes.[161] Red sore disease also has been noted in parts of the complex and strongly correlated with eutrophic conditions.[162] Ulcerative dermal necrosis too has been observed, though as mentioned previously, its exact causes are unknown at this time.[163]

ATLANTIC: NORTHERN STATES[164]

The Northern Atlantic coast, from the North Carolina/Virginia border to the Canadian border, contains many major bays, estuaries, and shallow coastal areas, and is graced with remarkably rich marine resources. It also is the location of extensive and intensive agricultural, urban and industrial development which has occurred for several centuries. Consequently, marine ecosystems in many parts of the region are polluted and degraded, sometimes severely. Among the most seriously affected bodies of water in the region are the Chesapeake Bay, the New York Bight, Long Island Sound, Narragansett Bay, Buzzards Bay, and Boston Bay. These areas are discussed individually after the following general overview.

Municipal and industrial discharges, and dumped sewage sludge and dredged material, are important sources of pollutants in this region; their quantity and composition vary from place to place. Pollutants from these point source waste disposal activities have been associated with various impacts in the region. Improvements have occurred in many instances since the late 1960s and early 1970s;[165] conversely, in other cases, deterioration has occurred.[166]

Eutrophication and hypoxia appear to be the most pervasive and serious consequences of pollution in the region. They occur in many estuaries and bays, and over wide, shallow areas of the continental shelf often quite distant from the original sources of the nutrients and organic material; such impacts are most severe south of Connecticut.[167] The problems are caused by a variety of factors, including natural changes in water quality and inputs of nutrients and organic material from numerous sources (municipal and industrial effluents, runoff, raw sewage, dredged material, combined sewer overflows).

Water and sediments contaminated with fecal coliform bacteria, metals and various other pollutants are common in many parts of the region. Bacterial contamination of the water, particularly from raw sewage in combined sewer overflows, sometimes results in the closure of beaches, in most cases temporarily but sometimes permanently.[168] Sediments in many areas contain elevated concentrations of contaminants.[169] Among the most seriously contaminated sediments are those in the James River estuary, the Patapsco River around Baltimore, the Hudson River estuary, Raritan Bay and the New York Bight, New Bedford Harbor, and Boston Harbor.

Many impacts on marine organisms have been linked, with varying degrees of certainty, to waste disposal activities. These include contamination of finfish and shellfish, major kills of fish and benthic organisms,[170] declines in major fisheries, decline of vital beds of submerged aquatic vegetation, changes in community structure, and increased incidence of disease and abnormalities.[171]

In the severely polluted Boston Harbor, for example, fin erosion and cancerous lesions have been found in winter flounder, a major commercial and recreational species.

Commercial harvesting is limited in 14 percent of productive shellfish areas, mostly because the shellfish contain high concentrations of bacteria. Over one-half of the shellfish beds in Boston harbor are closed, at an estimated annual loss of $4 million.[172] The size of the areas in the region in which harvesting is limited has been slowly increasing over the last five years, although there are localized exceptions to the trend.[173] In addition to being contaminated with pathogens, many fish and shellfish also contain elevated concentrations of other pollutants, especially metals and hydrocarbons. As with pathogens, these concentrations have sometimes been high enough to prompt officials to restrict fishing or harvesting.

Some of the most extensive and serious instances of contamination were associated with large releases of PCBs by industrial manufacturers into the Hudson River between circa 1950 and 1976 and into New Bedford Harbor (in Buzzard's Bay, Massachusetts) from 1947 to 1977. These have resulted in widespread contamination of some fish and shellfish, and diseases and abnormalities in some organisms.[174] Restrictions have been imposed on the fishing and sale of contaminated organisms over wide areas. In New Bedford Harbor, a total of eighteen thousand acres were closed to lobstering.

Impacts to submerged aquatic vegetation (SAV) and to birds also have been severe in some cases. The most important impact to aquatic vegetation in the region apparently results from the large-scale introduction of nutrients in coastal estuaries. This increases the amount of algae suspended in the water column above the SAV, depriving it of vital light. This along with other factors have destroyed large areas of SAV, a process which appears to have major repercussions on aquatic organisms of all kinds, including valuable fish and

waterfowl.[175] In addition, some birds have exhibited elevated concentrations of pollutants as a result of ingesting contaminated organisms.[176] In some cases these high concentrations led to reproductive failures and population declines. Such was the case for many decades with the fish-eating osprey. But restrictions in the production and use of DDT reversed the trend; and many parts of the region since the early 1970s have witnessed a dramatic increase in osprey populations.[177]

Of growing concern are the "brown tides," massive blooms of a phytoplankton[178] which have struck waters in parts of the region in 1985 and 1986. In 1986, these were concentrated in waters around the eastern tip of Long Island, New York; in Narragansett Bay, Rhode Island; and Barnegat Bay, New Jersey. The blooms have wiped out large areas of submerged aquatic vegetation and shellfish beds. Fisheries, such as Long Island's scallop industry, have been devestated. The causes of the blooms are not known; though pollutants such as phosphorous may be implicated, available evidence is not sufficient to ascertain whether pollutants are a significant factor.[179]

CHESAPEAKE BAY[180]

The Chesapeake Bay, the county's largest estuary, is located in Maryland and Virginia. Within its confines flow numerous rivers draining those states as well as parts of West Virginia, Pennsylvania, Delaware. Substantially sheltered from the forces of the open ocean, it harbors habitats rich with marine life. Submerged aquatic vegetation, of pivotal ecological importance, is extensive. Large populations of birds freqent the area. It is an annual stopping point for more than 1 million migrating waterfowl. More than 75 percent of the Atlantic flyway waterfowl population winters in the tidewater areas of the bay.[181]

Abundant and diverse fish and shellfish populations also are found in the bay and many use its waters as nursery areas. These support an extremely valuable commercial fishing industry, dominated by menhaden. The annual landings in 1985 in Virginia and Maryland, most of which originates from the Chesapeake, were nearly 815 million pounds -- about thirteen percent of the total U.S. catch. It was worth nearly $124 million -- over five percent of the value of the fish landed in U.S. ports.[182]

The bay's drainage includes extensive agricultural areas and several major cities; nearly 13 million people reside in the land around the bay.[183] Both point and non-point sources are significant contributors of pollutants to its waters, causing serious problems which in some instances appear to be getting worse. Among these, perhaps the most publicized has been the dramatic decline in the population of striped bass. Less apparent have been deleterious changes in the populations of benthic organisms and other species, including some of exceptional ecologic and economic importance.

Among the causes of the bay's problems is the addition of large volumes of nutrients, contributing to euthrophication and hypoxia. A considerable portion of nutrients originate with municipal sewage plants. Nutrient enrichment has been identified as a major cause for the dramatic decline in submerged aquatic vegetation,[184] declines in valuable fisheries,[185] declines in waterfowl;[186] and changes in benthic diversity, abundance and community structure.

Another problem in the bay has been the introduction of pathogens, metals, and various synthetic chemicals. Bacterial contamination has resulted in the closure of numerous shellfish beds in the bay and its tributaries. Metals and synthetic organic compounds too have contaminated and and sometimes

stressed organisms, including valuable fisheries. The problem is particularly serious in the Patapsco River near Baltimore, Maryland and the James River and its tributaries in Virginia.[187]

THE NEW YORK BIGHT[188]

The New York Bight is a 19,000 square mile area of the continental shelf which extends off the coasts of New York and New Jersey. In the north is the shore of Long Island, dominated by barrier islands; these protect an extensive system of bays and marshes. To the west is the shore of New Jersey. Here too, in the southern part of the state, are barrier islands with estuaries on the landward side; to the north are beaches, openly exposed to the ocean. At the apex (northwest corner) of the Bight, sandwiched between New Jersey and Long Island, is Raritan Bay, into which flows the Hudson and Raritan Rivers. From these coastal waters, the continental shelf extends far offshore.

Within this environment are extremely important habitats, including crucial nurseries and spawning areas. These ecosystems support valuable populations of fish, shellfish, and birds. Birds migrating along the Atlantic flyway rely on the area as a stopover point or as a place to spend the winter. Shellfish and fish, including anadromous species, support sizeable commercial and recreational fisheries. Recreational areas, including beaches and parks, and numerous wildlife protection areas such as National Wildlife Refuges are scattered all along the coast.[189]

The Bight receives large volumes wastes from New Jersey and New York -- states which include one of the largest urban and industrial concentrations in the world. Among the discharges are industrial and municipal effluent, large quantities of raw sewage, and dumped materials. Considerable amounts of dredged material also are dumped.

Nutrients have contributed to eutrophication and hypoxia, problems evident in many parts of the region.[190] Contamination of the sediments, water, and biota with pathogens, metals and synthetic organic chemicals also is extensive and in many instances severe. The presence of pollutants has resulted in a wide range of impacts. High concentrations of pathogens result in widespread restrictions on shellfishing. They also are evidenced by beach closures, both permanent and temporary. Furthermore, very elevated concentrations of PCB's have prompted restrictions on the fishing and sale of striped-bass over wide areas.[191]

In addition to resulting in high body burdens of contaminants, the pollutants are linked directly and indirectly to diseases and abnormalities; and to changes in abundance, distribution, and diversity of particular species and changes in community structure. Particularly significant have been the impacts on benthic organisms.[192]

LONG ISLAND SOUND[193]

Long Island Sound is a semi-enclosed body of water, about 90 miles (145 km) long and 15 miles (24 km) wide, located between Long Island to the south, Connecticut to the north, and New York City to the extreme west. It opens on the Atlantic to the east. The sound supports extensive and valuable shellfish beds; fish populations of considerable recreational and commercial importance are found there as well. Among the anadromous species found in the sound is the shortnose sturgeon, an endangered species. Numerous species of migrating birds concentrate in the area seasonally; among these are bald eagles, ospreys, and peregrine falcons. Some overwinter there. Several species of marine turtles and whales occasionaly transit the sound.

The sound is ringed by intense development which results in the discharge of a broad variety of pollutants. Pollutants also enter the sound through the area's rivers, including the Connecticut River, from sources located in its inland drainage area (extending into Canada). Major cities contributing pollutants along its periphery are the New York metropolitan area and several large cities in southern Connecticut. Point sources include municipal sewage treatment plants, industrial installations, and combined sewage overflows; dumping of dredged materials also occurs in the sound. Pollutant loadings are heaviest at the western end of the sound, especially near the East River, a tidal strait which connects Long Island Sound with New York Harbor.

Impacts to the marine environment in some instances are both serious and extensive, especially in the poorly flushed and heavily polluted western end of the sound. Eutrophication and hypoxia frequently are problems.[194] Bacterial contamination has resulted in restrictions in shellfish harvests, and periodic closures of beaches or recommendations against their use.

Contamination of the sediments, water column, and biota with metals and synthetic organic compounds (including PCBs) is extensive and in some cases severe, especially in the west end[195]. Degradation in the benthic environment, reflected in decreased species diversity, has been linked to pollutants as well.

NARRAGANSETT BAY[196]

Narragansett Bay, located at the southern end of Rhode Island and east of Long Island Sound, drains a large portion of Rhode Island and a lesser part of southeastern Massachusetts. The area supports large commercial shellfish beds and substantial recreational and commercial fish populations, including striped bass and winter flounder. Significant nesting areas for wading birds are found here, and some locations are used by overwintering waterfowl. In this area also are found many crawlouts and breeding areas for harbor seals.

The major cities along its shores are Providence and Fall River, Rhode Island. These urban areas discharge substantial volumes of pollutants to Narragansett Bay, among which are organic material, nutrients, pathogens, metals and synthetic organic chemicals[197]. Particularly problematic in the area are combined sewage overflows.

The consequences of the pollutants are multifold. Water, sediments and organisms are significantly contaminated with bacteria and toxic pollutants in portions of the bay.[198] Bacterial contamination has been high enough to result in the closure of many shellfishing areas and beaches[199]. The commercial sale of striped bass also has been forbidden because of widespread PCB contamination. Portions of the bay, particularly the upper part of the bay, also suffer from eutrophication and periodic hypoxia.

In the summer of 1985, a huge algae bloom or "brown tide" occurred in the bay, extending down to Rhode Island Sound; the phenomemon was repeated in 1986. Mortalities and other signs of stress were evident in sessile benthic organisms. As mentioned earlier, the precise causes of the bloom are unknown, though it is believed that it could be linked partially to extensive pollution of the area's waters.[200]

BUZZARDS BAY, MASSACHUSETTS[201]

Buzzards Bay is located along the southern coast of Massachusetts. A relatively small area of the southeastern part of the state, including New Bedford, drains into the bay. Large shellfish beds are found in many parts of the bay. Among the fish species of recreational and commercial importance are the anadromous alewife and American shad. Migrating bald eagles and peregrine falcons reportedly frequent the area. Of special importance is the bay's Bird Island, where the largest breeding colony of roseate terns in the U.S. is found; the colony supports 40 percent of the total U.S. population.

The most serious pollution problems within the bay are at New Bedford Harbor. Among point sources, municipal discharges -- including combined sewage overflows -- are most problematic in Buzzards Bay. The impacts observed in the bay include low concentrations of dissolved oxygen; bacterial contamination; and high concentrations of metals and synthetic organic chemicals in the sediments, water column and biota; and abnormalities and diseases in fish and shellfish.[202]

Most noteworthy is the severe contamination of New Bedford Harbor with PCBs. PCBs were manufactured in the area from 1947 to 1977, and large quantities were released to the marine environment during that time. Even though production had ceased by 1978, PCBs continue to enter the bay through various routes to this day. The entire bay therefore is contaminated extensively. In some areas, sediments have been found with PCB levels as high as 190,000 ppm (19 percent). Some finfish have had levels in excess of 100 ppm; the FDA allowable limit on PCBs in fish is 2 ppm (edible portion). Portions of the bay are so dangerously contaminated that they are subject to fishing restrictions. Eighteen thousand acres are closed to lobstering, while smaller areas are closed to fishing for other shellfish and fish (See Figure 13).

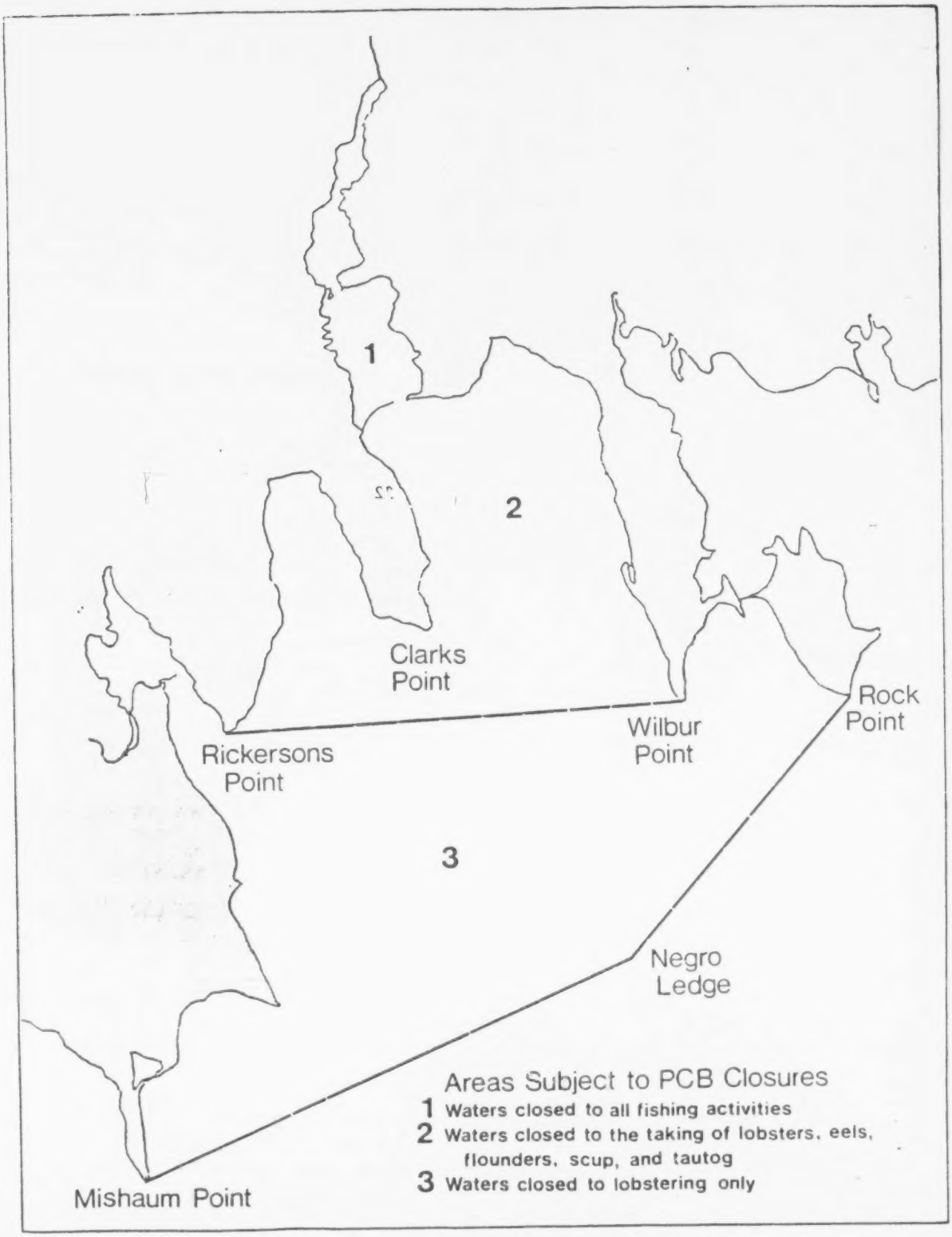
BOSTON BAY[203]

Boston Bay is located in the northeastern part of Massachusetts. This coastal area of the Atlantic is dominated by sandy beaches relatively exposed to the ocean. Among the important aquatic life found along the coast are submerged aquatic vegetation, fish and shellfish, and a large and varied population of birds. In addition, some marine mammals are common just offshore, though most species prefer more distant waters.[204]

The most economically important marine resources include commercial and recreational fisheries, and bathing beaches. Numerous State Beaches line the bay's shores. Large numbers of recreational fishermen spend part of their

FIGURE

Fishing Closure Areas Established by the Massachusetts Department of Public Health in the New Bedford Harbor Area.



Source: Massachusetts, Office of Coastal Zone Management, PCB Pollution in the New Bedford, Massachusetts Area: A Status Report (Boston: Massachusetts, Office of Coastal Zone Management, 1982), p 25.

leisure time in hopes of landing fish, principally flounder. Commercial fishing, dominated by clams, lobsters and flounder, also is of considerable importance in the area. The shellfish beds (mostly softshell clams) alone yielded annual harvests (circa 1983) of $5-6 million.[205]

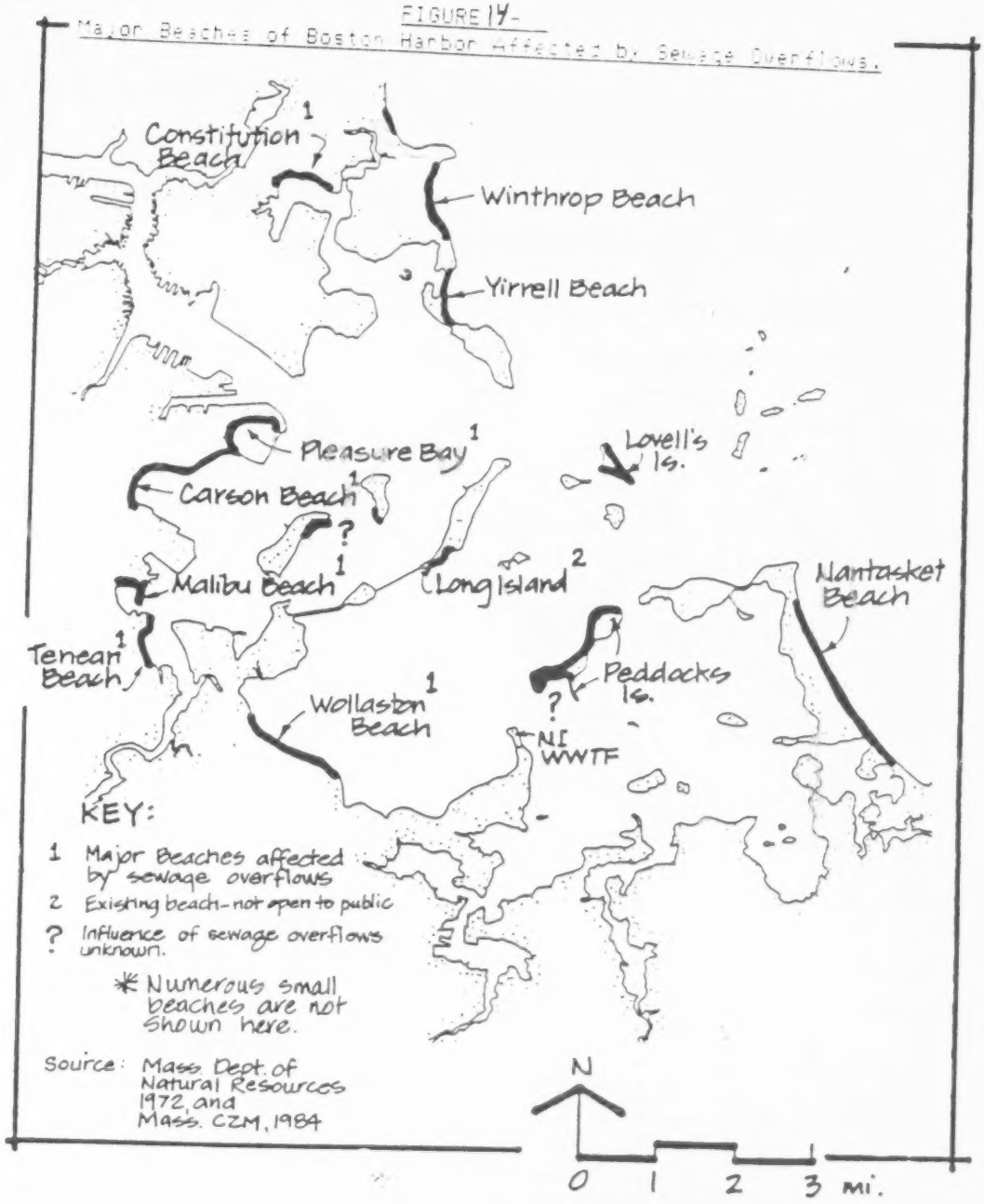
A large portion of the area draining into Boston Bay is occupied by the urban conglomeration centered on the city of Boston. Parts of Boston Bay are chronically polluted by a wide variety of substances including organic matter, nutrients, chlorinated hydrocarbons, metals, and pathogens. The contamination is most serious in Boston Harbor, the portion of the bay closest to the city; within the Harbor, the Inner Harbor is especially polluted. Among the sources of the pollutants are municipal sewage treatment plants, industrial facilities, and combined sewer overflows, both around the harbor and further inland.

Serious impacts have been linked to the pollutants. Floating sewage and other debris sometimes mar the water's surface. The sediments and biota are contaminated, sometimes severely. Over half of the shellfish beds in the harbor are closed, at an estimated annual loss of $4 million.[206] Swimming at the area's beaches is periodically restricted or discouraged (See Figure 14). Eutrophic and hypoxic conditions occur. The composition of benthic communities in some instances have been altered considerably. Diseases and abnormalities have been found in some of the harbor's fish and shellfish. Specifically, fin erosion and cancerous lesions have been found in winter flounder, a major commercial and recreational species[207].

**********END**********

FIGURE 14-

Major Beaches of Boston Harbor Affected by Sewage Overflows.



Source: CE Maguire, Inc., Boston Harbor Water Quality Baseline for the SDEIS on Boston Harbor Wastewater Facilities Siting (Providence, RI: CE Maguire, Inc., Dec 1984), Figure 2.

FOOTNOTES

[1] These regions are: 1) Northern Pacific Coast, 2) California and Hawaii, 3) Gulf of Mexico, 4) Southern Atlantic Coast, and 5) Northern Atlantic Coast.

[2] Ref. 106

[3] A photosynthetic organism is one which uses sunlight to synthesize compounds.

[4] "Brown tides" are massive blooms of a phytoplankton -- *Aureococcus anorexefferens* -- a type of algae unknown until it first was observed in 1985. In 1986, these were concentrated in waters around the eastern tip of Long Island, New York; in Narragansett Bay, Rhode Island; and Barnegat Bay, New Jersey. The blooms have wiped out large areas of submerged aquatic vegetation and shellfish beds. The causes of the blooms are not known; hence its connection with waste disposal has not been ascertained. For more information see the "Atlantic: Northern States" regional section below.

[5] The precise conditions needed for the initiation, propagation, and maintenance of both brown and red tides are not completely known. It is known, however, that nutrients are required for a bloom to proceed. If nutrients from waste disposal have enriched marine waters, they may in fact permit a bloom to be greater (and hence more damaging) than it otherwise would be.

[6] See refs. 479, 765, 791.

[7] Ref. 637.

[8] Ref. 579

[9] Ref. 931.

[10] Ref. 999.

[11] See Refs. 143, 636, 673, 762, 931, 1000, 1007.

[12] See Refs. 637, 654.

[13] See Refs. 538 (p.139-147) and 673.

[14] See Refs. 3 (p. 64), 257 (p. 20), 298 (p. vi-vii), 312 (p. 9 and 43), 469 (p. A-III-89), 538 (p. 139-147), 542, 550, 627 (60-61), 673 (p. II-24), 808 (p. 539-540), 1007 (p. 9-11, 20-21).

[15] See Refs. 298 (p. 43, 137, 168), 579, 673 (II-28 and II-29), 805, 1007 (p. 9).

[16] The surface microlayer consists of a thin layer in the upper part of the water column; it commonly is considered to be about 50 micrometers in thickness.

[17] Ref. 887 (p. 40).

[18] Ref. 553 (p. 14-15).

[19] Ref. 118 (p. 91).

[20] See Refs. 112 (p. 4 and Fig 2), 278, 460 (p. 85), 538 (p. 139-147), 673 (II-27 and II-28.).

[21] Ref. 542.

[22] See Refs. 284 (p. 95a) and 460 (p. 85).

[23] For other examples, see Refs. 257 (p. 20) and 673 (V-216 through V-218).

[24] See Ref. 298 (p. 148, 168), 501, 538 (p. 139-147).

[25] Ref. 421.

[26] See Refs. 421, 503, 808.

[27] Ref. 261.

[28] This is the abbreviated name of 1,1,1-trichloro-2,2-bis-(p-chlorophenyl(ethane), $(p\text{-}ClC_6H_4)_2CHCCl_3$.

[29] For example, see Ref. 126.

[30] Ref. 18.

[31] See for examples Ref. 299 and 538 (p. 139-147).

[32] See Ref. 239 and 299 (p. 62).

[33] See Refs. 118, 299, 431, 627, 662.

[34] See Refs. 29, 77, 95, 126, 159, 272, 431, 695, 785.

[35] Ref 890.

[36] See Refs. 261, 425, 431, 489, 906.

[37] Ref. 75.

[38] See Refs. 425, 489, 906.

[39] See for example Ref. 299.

[40] See Refs. 467, and 906.

[41] Note that while most of the PCB contamination originated from the General Electric facilities, sizeable quantities entered the environment from other sources, most notably the local sewage systems.

[42] Ref. 569.

[43] See Refs. 294, 295, 915.

[44] Ref. 913.

[45] See Ref. 91, 586, 589.

[46] Ref. 1003.

[47] See Refs. 126, 585, 587, 669.

[48] See Refs. 186 and 263.

[49] Ref. 368.

[50] Ref. 8.

[51] Ref. 237.

[52] Ref. 695.

[53] EPA Form 7500-8. The most recent version of this form (Revised April 1986) is called a "Report of Pollution-Caused Fish Kill or Abnormality."

[54] These are biennial reports issued by State Governments on the status of their waters, submitted to the federal government in accordance with Section 305(b) of the Clean Water Act.

[55] See Refs. 421, 503, 808.

[56] Ref. 621.

[57] Ref. 621.

[58] Harllee, Nina (Monitoring and Data Support Division, Assistant Administrator for Water, Environmental Protection Agency), conversation with OTA staff, 17 March 1986.

[59] Ref. 897.

[60] See 421, 503, 299.

[61] Ref. 14.

[62] Ref. 96 (p. 77).

[63] See Ref. 298 (p. 148, 168), 421 (p. 14-15), 501, 503 (p. 22), 538 (p. 139-147).

[64] See Refs. 95, 661, 718, 766, 890, 906.

[65] Capuzzo, Judith M. et al., "Bioaccumulation and Biological Effects of PCBs on Marine Bivalve Molluscs in New Bedford Harbor, Massachusetts," p. 110-112 in Ref. 734.

[66] Ref. 95.

[67] Ref. 95.

[68] Ref. 473.

[69] Ref. 277.

[70] See Refs. 247, 890, 906, 919.

[71] See Refs. 45, 471, 627, 737, 971, 865. See also Huggett, Robert J. and Nichols, Maynard M. and Bender, Michael E., "Kepone Contamination of the James River Estuary," p. 33-52 in Ref.20.

[72] The body-burden of a contaminant is its concentration in an organisms body.

[73] General surveys of the field include Refs. 194 and 661.

[74] See for example Refs. 277 and 763.

[75] Pipeline discharges or dumping of organic matter and nutrients, for example, may increase productivity of marine waters. Some argue that this increased productivity has in some cases been beneficial. See Ref 708.

[76] See Refs. 471 and 518.

[77] See Refs. 752 and 987.

[78] See Refs. 435, 524, 627.

[79] See, for example Refs. 62, 80, 118, 159, 210, 212A, 228, 369, 471, 479, 489, 518, 553, 555, 599, 599A, 599B, 647, 732, 785, 790, 890, 906, 1014, 1019.
See also:
--Luoma, S.N. and Cloern, J.E., "The Impact of Waste-Water Discharge on Biological Communities in San Francisco Bay," p. 137- 160 in ref 376.
--Capuzzo, Judith M. et al., "Bioaccumulation and Biological Effects of PCBs on Marine Bivalve Molluscs in New Bedford Harbor, Massachusetts," p. 110-112 in Ref. 734.

[80] See for example Refs. 402, 553 (p. 14-15), 987.

[81] Ref. 402.

[82] See Refs. 553 (p. 14-15), 555 (p. 71-73), 677 (p. 40), 750 (p. 72-73), 887 (p. 39-40), 931 (163-183), 987.

[83] Ref. 680.

[84] As used here, this term is synonymous with "submerged vascular plants," which include types of algae and angiosperms.

[85] See 298 (p. 43, 148, 207) and 412.

[86] See Refs. 597A and 931.

[87] See the discussion of the Chesapeake Bay in the section on the northeast, later in this report.

[88] Ref. 34.

[89] Harrison, W. "Environmental Effects of Dredging and Spoil Deposition," p. 535 in Ref 1006.

[90] See Refs. 287, 479, 538 (p. 139-147), 766, 795, 906.

[91] Ref. 784.

[92] See Refs. 156, 356, 489, 595, 609, 627. See also Hood, Donald W. and Goering, John J., "Pollution Problems in the Estuaries of Alaska," p. 285-296 in Ref. 928.

[93] See for example Ref. 781.

[94] Ref. 596.

[95] Ref. 627 (p. 37).

[96] Ref. 39.

[97] Ref. 627 (p. 41).

[98] Ref. 627 (p. 50).

[99] See Ref. 91, 416, 416A, 417, 436, 440, 473, 627, 662, 906.

[100] See Refs. 11, 25, 52A, 92, 117, 118, 118, 119, 120, 122, 250, 378, 381, 428, 428, 429, 431, 432, 435, 437, 438 441, 442, 443, 489, 524, 662, 797, 807, 942 (p. 15). Based also on information obtained from conversation between Donald C. Malins (Director, Environmental Conservation Division, N.W. and Alaska Fisheries Center, National Oceanic and Atmospheric Administration) and OTA Staff, Feb 5 1986.

[101] Ref. 389.

[102] Major sources of information on California include Refs. 95, 96, 97, 98.

[103] For information on Hawaii's waters, see Refs. 199A, 312, 443A, 588, 781, 742. See also Smith, Stephen V., "Environmental Status of Hawaiian Estuaries," p. 297-306 in Ref. 928.

[104] See Refs. 95, 96, 489, 906.

[105] See Refs. 12 (p. 3), 138, 542; and Russell, Peter P. et al., "Water and Waste Inputs to San Francisco Estuary--An Historical Perspective," p. 127-136 in Ref. 376.

[106] See Ref. 39.

[107] See Refs. 200 and 714.

[108] Ref. 667.

[109] See Refs. 123, 324, 387, 431, 455, 473, 489, 586, 589, 666, 750, 752, 772, 987, 988. See also:
--Luoma, S.N. and Cloern, J.E., "The Impact of Waste-Water Discharge on Biological Communities in San Francisco Bay," p. 137- 160 in Ref. 376.
--Russell, Peter P. et al., "Water and Waste Inputs to San Francisco Estuary--An Historical Perspective," p127-136 in Ref. 376.
--Sevareid, Robin and Ichikawa, Gary, "Physiological Stress (Scope for Growth) of Mussels in San Francisco Bay," p. 152-170 in Ref. 745.

[110] Ref. 39.

[111] Ref. 252.

[112] Ref. 501.

[113] This problem has been alleviated with the opening in January 1987 of a new sewage treatment plant in Tijuana, Mexico. Furthermore, under an international agreement, Tijuana will divert sewage to the city of San Diego for treatment when currents otherwise could send pollutants north into U.S. waters. The new Mexican plant, along with the periodic assistance of the U.S. plant, is expected to greatly alleviate problems of bacterial contamination in U.S. waters close to the border.

[114] See Refs. 79, 272, 585, 695.

[115] See Ref. 473, and Risebrough, Robert W. and Jarman, Walter M. and Chartrand, Allan B., "Environmental Effects of Ocean Dumping at two Sites in the San Pedro Channel of the Southern California Bight," p. 108-109 in Ref. 734.

[116] Steinman, David, "Contaminated Catch (Part II)," L.A. Weekly , 8 (13): 28-30, Feb 21-27, 1985.

[117] See Refs. 770, 865.

[118] Ref. 865.

[119] See Refs. 8, 34, 56, 126, 159, 161, 162, 163, 186, 263, 272, 282, 347, 387, 420A, 455, 457, 488, 491A, 510, 587, 665, 666, 668, 669, 677, 695, 699, 717, 772, 776, 777, 781, 798, 865, 1012.

[120] See Refs 8, 29, 78, 126, 165, 488, 431, 489, 785.

[121] Ref. 75.

[122] Ref. 473, 491.

[123] See, for example, Reish, Donald J. and Biksey, Thomas and Ware, Richard, "The Effect of the Change in Municipal Waste Treatment on Marine Benthic Communities," p. 234-245 in Ref. 745.

[124] Ref. 421, 503, 808, 947 (Chapter 4).

[125] Ref. 38.

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[127] Refs. 3, 230, 253, 298, 301, 421, 503, 623, 636, 802, 808, 1007.

[128] Refs. 261, 298, 368, 411, 421, 451, 503, 599, 661, 808.

[129] Refs. 3, 13A, 298, 421, 503, 808, 897.

[130] Refs. 212A, 599, 599A, 599B.

[131] Refs. 253, 298, 502, 412.

[132] Refs. 421 (p. 12), 654, 680.

[133] Refs. 367, 368.

[134] Refs. 136, 404, 405, 407, 409, 410, 1018.

[135] Refs. 3, 298.

[136] Refs. 3, 212, 298, 299, 508, 808.

[137] Refs. 3 (p. 59), 212, 411 (p. 5), 421 (p. 14), 503 (p. 22), 808 (p. 542).

[138] Ref. 420

[139] For general surveys, see Refs. 238, 257, 371, 551.

[140] Ref. 40.

[141] See Refs. 14, 257, 298.

[142] In addition to the section below on the Pamlico-Albermarle estuarine complex, see Refs. 24, 298, 371 (p. 2 and 23), 551.

[143] Ref. 897.

[144] See Refs. 185 (p. 67-69), 298, 344A, 683.

[145] Based on conversation between Thomas D. Matthews (South Carolina Wildlife and Marine Resources Dept) and OTA Staff, 24 March 1986; and on Ref. 371.

[146] Ref. 551 (p. 192).

[147] Ref. 257.

[148] See Refs. 298 and 299.

[149] Ref. 239. Samples were not taken for the 1980-1985 period; trends during that period therefore cannot be ascertained.

[150] See Refs. 24, 298, 344A, 371, 762, 2007,

[151] See Refs. 15 and 412.

[152] Ref. 344A.

[153] See Refs. 69 (p. 1), 298, 551, 553 (p. 14-15), 555, 680, 805.

[154] Ref. 552 (p. 27).

[155] See Refs. 210, 298, 546, 547, 551, 690.

[156] Ref. 62 (p. 1).

[157] See Refs. 69 (p. 1), 551, 552, 553 (p. 14-15), 555, 556, 805.

[158] See Refs. 40, 153 (p. 75), 226.

[159] See for example Ref. 226 (p. 41-47).

[160] See Refs. 69 (p. 1), 153 (p. 75), 551 (p. 117-119), 552 (p. 56), 970 (p. 84).

[161] Refs. 551 (p. 79-80 and 117-119), 552, and 555 (p. 69-77)

[162] Ref. 226, p. 40

[163] See Refs. 210, 546, and 551 (p. 79-80 and p. 117-119).

[164] Major sources of information on the marine impacts of pollutants in this region include Refs. 148, 184, 460, 471, 479, 657, 890, 903, 931, 970, 1000.

[165] See Refs. 148 (p. 27-32), 460 (p. 85), 469 (p. A-III-89), 538 (p. 139-147), 548 and 663.

[166] See for examples Refs. 538 (p. 139-147) and 469 (p. A-III-19).

[167] See Refs. 393, 460, 469, 538 (p. 139-147), 579, 482, 970, 1000.

[168] See Refs. 112, 278, 393, 460.

[169] Ref. 718.

[170] See, for example, Ref. 718.

[171] See Refs. 45, 228, 460, 482, 518, 672, 657, 718, 766, 970, 1014, 1019.

[172] Ref. 112 (p. 4).

[173] See Refs. 373 and 897.

[174] See Refs. 369, 467, 469, 647.

[175] See Refs. 597A and 931.

[176] Refs. 237 and 366.

[177] Ref. 753 and 1003.

[178] *Aureococcus anorexefferens*, a previously unknown type of algae.

[179] See Refs. 372, 375, 525, 657 (p. E-4 through E-6).

[180] Information for this section was drawn primarily from Refs. 83, 84, 86, 87, 270A, 294, 295, 296, 325, 359, 459, 579, 597, 621, 622, 711, 789, 867 (esp pages 31-32), 931, 971, 987A . See also Lippson, R.L. and Lippson, M.J., "The Condition of Chesapeake Bay--An Assessment of Its Present State and Its Future," p. 58-80 in Ref. 612.

[181] Ref. 40.

[182] Ref. 891A.

[183] Ref. 459.

[184] Ref. 912.

[185] See Refs. 915, 916.

[186] See Refs. 913, 914.

[187] See Refs 718, 970. See also Huggett, Robert J. and Nichols, Maynard M. and Bender, Michael E., "Kepone Contamination of the James River Estuary," p. 33-52 in Ref. 20.

[188] See Refs. 18, 537, 663.

[189] Ref. 40.

[190] See 673, 779, 791.

[191] See Refs 80, 559, 737.

[192] For further information, see 47, 66, 80, 155, 218, 243, 276, 286, 300, 333, 369, 373, 374, 377, 419, 479, 480, 494, 516, 538, 559, 560, 604, 610, 645A, 673, 691A, 700, 737, 757, 766, 767, 795, 796, 871, 934, 973, 986, 1000, 1003, See also:

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198 Ref. 81.

199 Ref. 278.

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203 Based primarily on information on Refs. 47, 112, and 469.

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